Hardy nursery stock propagation guide

Contents

The information in this guide was complied by Andrew Hewson, ADAS. AHDB is grateful to all those who have commented and contributed to this publication.

Foreword

Since its inception, AHDB Horticulture has funded a considerable amount of research relating to hardy nursery stock (HNS) propagation. During this period and before it, Defra also supported a significant programme of research and technology transfer on hardy nursery stock plant propagation, much of which was complemented by AHDB Horticulture-led work. Notable examples include work undertaken at the former ADAS Experimental Horticulture Stations HRI Efford and Luddington and NIAB East Malling Research station, on stock plant management, chip budding, propagation environments, substrates, nutrition and micropropagation.

The principal findings from this work are widely scattered throughout numerous project reports and associated references, including EHSs open day handouts, annual reports, summary reports, reviews and, more recently, various AHDB Horticulture factsheets. There is also a wealth of information of value to the hardy nursery stock industry from other sources, most notably the Annual Proceedings of the International Plant Propagators' Society (IPPS). However, because the information is so widely dispersed, it is difficult and time-consuming for growers to access and evaluate it and then apply or adapt the key findings to their own nursery situation in order to improve propagation performance.

As a result, AHDB Horticulture commissioned ADAS to collate this information with the principal aims of summarising existing knowledge, critically reviewing it and assessing new advances, in order to produce a practical ***Hardy nursery stock propagation guide***.

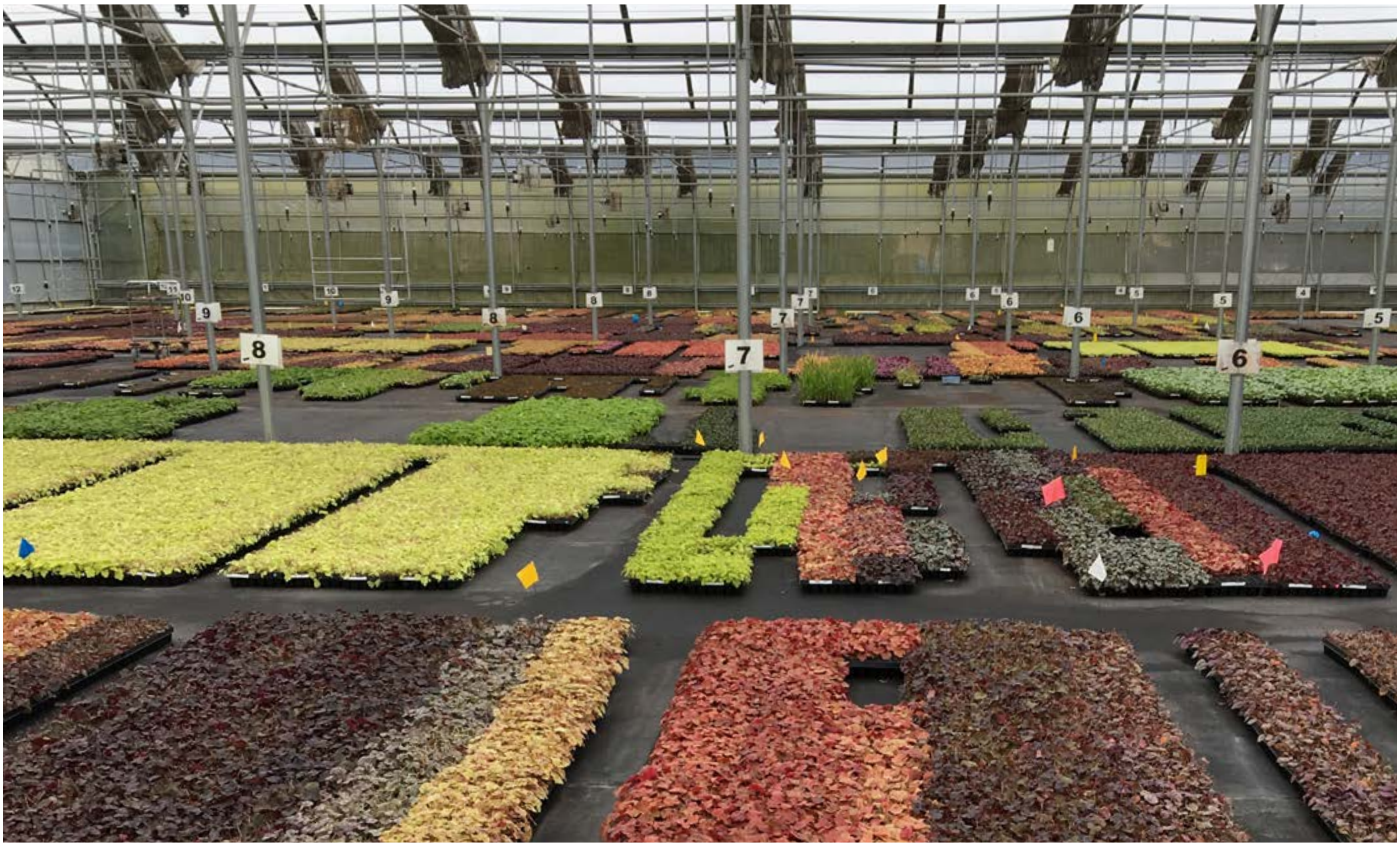
For ease of reference, the guide is divided into six main sections, encompassing propagation management, propagation techniques, propagation environments and systems, aftercare, a series of practical propagation summaries from the IPPS and industry research and knowledge transfer requirements. Case studies are featured throughout to illustrate good practice and show how leading growers have applied new technologies to improve propagation outcomes.

A number of appendices are also included at the back of the guide providing information on dealing with common problems encountered and detailing the propagation methods for a range of HNS subjects.

While aimed primarily at the experienced propagator, the ***Hardy nursery stock propagation guide*** is also intended for use as a training aid for use with students and new staff members. As such, it is structured in a readily extractable format that can be adapted and used for bespoke nursery-specific training. It is also easy to navigate, featuring signposting to further, important sources of information. The guide also features numerous illustrations in the form of charts, tables, graphs and images to show and summarise key points.

AHDB Horticulture is grateful to Andrew Hewson of ADAS for leading this work and developing the guide. AHDB Horticulture would also like to thank the IPPS for its commitment and contribution to the project and each of the growers who have contributed to the guide, especially those who have participated in the case studies.

Ian Ashton, Lowaters Nursery



Propagation management

Do it yourself or buy in?

Thought should always be given before developing a new enterprise or extending an existing one that it is the correct decision to be undertaken. Could some or all of the plant material be bought in from other, specialist suppliers? Is, for example, buying in unrooted cuttings a viable alternative? Might outsourcing be a cheaper, less wasteful and more flexible option and one that doesn't tie up capital, space and other resources for lengthy periods? Table 1 summarises the benefits and risks behind the decision.

There isn't a standard answer to the question of whether to propagate or buy in as different nurseries have different needs and much depends on individual circumstances. In reality, growers often compromise and focus their resources on what they know and grow well while buying in those crops with which they have difficulties from specialist producers. Outsourcing does help release valuable time and space to focus on other activities or crops.

Plant material can be purchased as unrooted cuttings, rooted plugs or established young plants in 7, 8 or 9 cm pots (liners). Buying in unrooted cuttings from specialist propagators works well for some businesses. Often, such material is imported from the Mediterranean area (notably, Israel) where stock plants from which cuttings are harvested are grown in a warmer climate with longer days, which may suit year-round production.

However, supply chain problems and associated costs, may ensue when buying in all kinds of plant material and these should be taken into account. There is also a risk of importing non-indigenous quarantine pest and disease problems and it is also less easy to monitor trueness to type.

Developing a propagation unit

The principal aim of any propagation enterprise is to produce a sufficient number of well-graded, healthy, high-quality plants as economically as possible to secure good returns.

Table 1. The benefits and risks of in-house propagation and buying in

In-house	Bought in
Benefits	**Benefits**
Quality control and independence Reliability to customers, self-sufficiency and security of supply Opportunity to exploit market opportunities created by those who have reduced or abandoned propagation Attractive to staff and enables specialist skills to be retained by the business Utilises existing space and facilities throughout the year Usually cheaper where skills and suitable facilities are in place and can be developed Closer control of costs and programming Easier to manage and control the development of new plants Less risk of pests, diseases and weeds being brought onto the nursery Works well where continuity of supply is required, especially small runs of less common lines	Obviates need to invest in costly facilities for in-house propagation or to expand existing facilities Frees up time for other developments Specialist propagators can offer improved quality, uniformity and the ability to help schedule finished crops Flexibility to respond quickly to changing market trends and requirements Convenience Fills in-house skill gaps where propagating skills have diminished In-house time, space and resources are released to use on other activities or crops the nursery wants to focus on Usually less waste if difficult crops are left to specialists Avoidance of the need to manage and maintain stock plants
Risks	**Risks**
Space, staff and equipment are tied up making it difficult to respond quickly to market trends Plant licensing arrangements may preclude in-house propagation of particular plants Stock plants or nursery crops are required to supply propagation material Stock plants require time and space to manage May not make best use of existing resources Wastage can be high with difficult crops Loss of in-house propagation skills may make propagation of some subjects difficult to continue with	Usually more costly, especially as transport costs rise Quality can be variable Can be difficult to outsource rare, unusual or specialist plants Not so easy to contain costs It can be difficult to find what you want when you need it and in the required quantity Potential lack of reliability May bring pests, diseases and weeds onto the nursery Rising costs of plant health inspections associated with imported material

Planning considerations

An important consideration when developing or extending a propagation unit is to 'keep it simple' and stay within any financial budgets. Avoid unnecessary, overly sophisticated equipment that may be costly and unlikely to be used. Expensive equipment isn't necessarily the best and simple systems will often deliver the most successful results.

There are some important points to consider:

- What about planning and building regulations requirements? These should be checked out with your local authority at the start
- What crops are to be propagated, which techniques will be used and what facilities are required?
- What are the plant numbers involved and how much space of which facility type is required?
- Will propagation be combined with liner production on this site, in which case more space will probably be required?
- Will stock beds be used and established on the site, either as an adjunct to existing beds or as replacements?
- In the case of open ground herbaceous, a 'dirty area' for initial division is a good idea, as is a washing-off area to keep soil out of the main unit
- What other facilities will be needed (including covered work space, cold storage, growing room, staff room, car parking, equipment storage) and do these need to be new or can the new development be linked to existing work areas?
- Think carefully about the allocation of space and relationships between stock beds, propagation unit and storage areas, as well as access
- What sort of transport and handling system will be used and how will this impact on site development, such as bed area and their configuration, pathways and access areas?
- Where is the best location for the new or expanded unit?

Site considerations

The next step is to think about the site and, in particular, the following requirements.

Drainage and shelter

Choose a well-drained and well-sheltered site if possible, strong winds are damaging and create heat loss from glasshouses. Use windbreaks where necessary but site these carefully so they give maximum protection without casting undue shade.

As a guide, windbreaks relative to a glasshouse block should be an optimum height of two-thirds of the height of the ridge and sited so that the distance between the windbreak and the glasshouse block is three times the eventual height of the windbreak. Living windbreaks should be thinned periodically to give 50% porosity and so provide a steady filtering of strong winds. Internal windbreaks may be needed on larger sites and should also provide 50% porosity and be well secured against strong winds.

Topography and shape of site

Ideally, the site should also be reasonably level, that is, slope no more than 1:75. The shape of the site isn't of great significance but regular shapes enable best use of space and are much easier to work with.

Layout of site

Careful planning helps make the most efficient use of all resources, particularly machinery and nursery staff. Much of this will be influenced by the prevailing or proposed handling and transport system. During site planning, take account of common bottlenecks such as preparation and potting areas. Think carefully about:

- The entrance area and general access. Preferably, this should be centrally located and lead directly to the car park and office/staff areas
- The preparation area and production structures. These should lead on from the office and staff areas and combine preparation space for sorting and grading stock plant material, handling and inserting cuttings and potting. Locate cold storage and growing room facilities nearby
- An orbital road. This should lead out from the car park, past the production building and service the rest of the site. It should follow a circular route because this is usually more space effective than providing vehicle turning areas. The surface should be smooth and firm. A width of 4.5 m should enable vehicles to pass
- Beds and pathways. These should be of a standard size and linked with the chosen transport system. As a guide, the preferred handling distance from pathway to setting-down point on a bed is 2–3 m; any wider, then the work becomes harder and slower and, so, more costly. Narrow paths between beds for trolleys should be around 1 m wide and wider paths suitable for mini-tractors, forklifts and pallet trucks should be 2 m
- Bed construction. Beds used for propagation and growing on liners must be well drained; capillary sand beds are ideal for producing uniform crops with clean foliage and minimum weeds. Permeable membranes can be used to control weeds and rooting through. Base heat can be installed for propagation. Heated floors of porous concrete construction make good use of space and are easy to clean
- Room for expansion. It's not always necessary to develop the whole site in one go but phased developments should take account of future plans and allow for any possible changes

Water supply

An adequate supply of water suitable for crop irrigation is essential and extra capacity may be needed when expanding existing facilities. Water used in fogging propagation systems should be drawn from a clean, direct mains supply to help safeguard staff (from contracting *Legionella* via inhalation of the fog). Enclosing fog units within high polythene tents provides a further safeguard.

Water quality is particularly important for propagation, especially where mist and fogging systems are deployed. 'Hard' water is likely to block jets over time and discolour crop foliage and high salt levels may also scorch seedlings or cuttings. High water alkalinity (above 200 mg/l calcium bicarbonate) can also trigger excess callusing of cuttings and be detrimental to rooting. Acidification of irrigation water should be considered if water alkalinity is an issue.

Power supply

An adequate and reliable three phase power supply will be required for lighting, supplementary lighting, heating and general use.

Layout of propagation structures

Multi-span constructions make the best use of available space, with compartments for accommodating different propagation or growing zones. Integrating areas in this way is efficient and provides flexibility.

Work areas should be in a dedicated space that is linked internally to the propagation areas to increase the speed of handling of sensitive cutting material. Production houses with corridors are ideal. Key points include:

- Check planning and building regulations requirements with your local planning authority before developing anything
- Cost items out carefully to ensure you have an adequate budget
- Design propagation beds or benches around an integrated materials handling system and ensure all work, propagation and growing areas are joined up, such that plant material can be seamlessly moved from one to another when ready, preferably under cover
- Include a plant material storage area for cutting preparation and one large enough for receipt of bought-in plant material such as rooted plugs or liners
- Use mobile work benches, with wipe-clean surfaces for flexibility and ease of cleaning
- Avoid clutter and make work areas comfortable with adequate heat and good natural light
- Use sliding doors for easy movement of materials and to increase light and ventilation when required. Make sure the walls and roof are insulated to conserve heat energy
- Allow sufficient space for good, safe access both inside and around the glasshouse; main pathways should accommodate pallet trucks
- Gantry systems make excellent use of available space in and around propagation areas, functioning either as work platforms or irrigation booms but they are costly and require large areas of free, unobstructed space to work

The following two case studies (overleaf) illustrate how two leading nurseries have planned and developed new propagation facilities.

Planning, programmes and record-keeping

Planning

Plan ahead to ensure adequate resources, including staff, facilities and propagation materials are available when required. Propagation facilities are usually costly so they need to be at or near to full capacity for as much of the year as possible.

In situations where year-round propagation is not feasible, such facilities could be profitably used for other purposes such as growing on liners or short-term container-grown crops to maximise throughput. Heated beds or floors, for example, can be used for spring and summer cuttings and winter bench grafting. Cold frames or sun tunnels often suffice for many conifer, heathers, semi-ripe and hardwood cuttings.

Some aspects of propagation such as bench grafting also require skilled and experienced staff while other tasks like summer and winter cutting preparation can be frequently undertaken by seasonal staff who have received the necessary training.

Ensure sufficient space is available for rooted cuttings to be weaned and young plants to be grown on.

Devising a propagation programme

Most nurseries have some form of propagation programme, devised as part of the forward-planning process, which should reflect staff, space and propagation material requirements. There is no standard programme and, while they usually vary in their level of detail, sophistication and the method of presentation, they need not be complicated.

The programme should focus on crops that suit the available skills and facilities. Ideally, these should be those in short supply that can be propagated successfully in-house with the best returns and lowest risk of failure. Buy in those that are difficult or uneconomic to produce in-house or where market demand is uncertain.

Successful propagation depends on good timing, when cutting material is in the optimum condition for rooting. This is more crucial with some subjects than others, for example, the spring propagation of deciduous *Azalea*, *Magnolia* and *Syringa* from softwood cuttings.

Cuttings of some herbaceous subjects must be taken when vegetative rather than floral for best results, for example, *Epimedium*, which is best taken in late spring after flowering.

Similar remarks apply to seed harvesting and germination, as well as propagation by grafting and budding.

Case study 1: West End Nurseries

Preparing and planning for a new propagation unit

West End Nurseries in Devon is run by Peter van Delft and specialises in the propagation of shrubs and climbers for the trade. They invested in a new facility in 2000 to improve production efficiency and satisfy a rising demand for quality liners. "It was becoming more difficult to buy in the plants that our customers wanted and prices were increasing, exacerbated by rising transport costs," explains Peter. "With some competitors abandoning propagation, we also felt investment was timely, enabling us to improve service levels to our customers," he adds.

"Throughout the planning process," Peter continues, "be aware of the market around you; it may be that for some lines it becomes more economical to buy in; changes occur rapidly and your plans need to be sufficiently flexible to enable you to respond quickly. Also, clearly establish what you need from the new unit; at West End Nurseries, we needed improved efficiency, more capacity, greater flexibility and reduced running costs and, so, factored these into our planning.

"We also wanted to grow better quality liner crops by reducing stress on our propagation material with better facilities improving the rooting of cuttings. Higher productivity can be achieved by shortening rooting times and improving labour efficiency and the working environment for staff," advises Peter.

He continues, "When planning, stay abreast of research developments and new technologies, too; we were especially keen on using IPM, improving disease prevention and reducing rooting times. When making a big investment like this, try also to make it as 'future-proof' as possible so that it doesn't become dated or constrain expansion going forward. We aimed to ensure our new facility would enable us to expand and develop new markets. Flexibility is the key.

A mechanical lift allows benches to be moved between two levels

Try to also build in safeguards through thorough risk assessments and plan contingencies in case of failures.

"When it comes to site preparation, ensure the terrain is suitable and you can cope with drawbacks; our new unit is on a sloping site, so we had to put in a mechanical lift to move our benches between two levels. The location of the unit within the nursery and access to it are also important considerations. Remember too, that it's very easy for costs to spiral, so allow for a 20% overrun in your costings and be sure to have full control over all developments. Think, too, about staff resources as this can make or break the efficiency of a new enterprise; some staff may need to relocate, travel further or learn new skills.

Mobile benching in the propagation unit

"Think about your plant range in relation to the planned facilities; there may in fact be scope to expand this and grow crops previously not possible. Conversely, a more specialist approach could be the way forward. Balance opportunities with the risks of overproduction."

West End Nurseries' careful planning led to the completion of their new propagation unit in 2003, featuring 2,350 m^2 of Venlo style glasshouse with 13 spans, roller benches, workbenches for preparing and sticking cuttings, a scissor lift to move benches between the two levels of the propagation house, environmental computer control, thermal shade screening, a cold store and weaning unit.

Reflecting on the project following completion, while Peter is pleased with the results, he also recognises some errors. "Even though we planned carefully, we did make mistakes," he says. "We didn't allow enough time to learn how to use the new facility before it was commissioned and it should have included more storage space. We also didn't set aside sufficient funds to complete the unit in its entirety. In some cases, we also relied too heavily on advice from consultants rather than our own knowledge," he concludes.

Case study 2: Palmstead Nurseries Ltd

Developing a new propagation unit

Kent-based Palmstead Nurseries Ltd grows a wide range of nursery stock for the landscape and amenity market, including container and field-grown crops. They propagate much of their requirement, using a combination of mainly field-grown stock plants and nursery crops for propagation material.

The nursery employs a range of propagation methods, mainly cuttings but also seed (early spring sowings direct into modules), division (various herbaceous and grasses) and bench grafting using hot-pipe callusing (*Betula*, *Fagus*, *Corylus* in winter followed by *Hamamelis* and *Viburnum* in summer). Evergreen *Prunus* are direct stuck during late September to early October and rooted cold under contact polythene, a cheap and effective way of propagating an important, high volume crop.

In 2010, Palmstead Nurseries opened its own brand new propagation unit to boost in-house production and meet the rising demands of the nursery for uniform, high-quality liners.

Occupying an area of one hectare and costing in the region of £1 million, the new unit comprises a multi-span glasshouse block that integrates four different environmental zones for propagation and weaning with growing on beds for rooted cuttings and a work area for propagation. At £1 million, the unit represents a substantial outlay but the business is committed to propagation and keen to be as self-sufficient as possible. “We enjoy propagation and want to do more,” says Young Plants Manager Geoff De La Cour-Baker. “Our need for young plants continues to grow and we like the quality control, flexibility and self-sufficiency that in-house production gives us. We’d outgrown our old space and decided to invest in new facilities to keep pace with demand,” he says.

The facility combines sophisticated environmentally controlled propagation zones with spacious compartments for accommodating rooted material and liners, all under one roof.

Fog/misting system in the propagation unit

Nursery Technical Manager Lee Woodcock explains more. “A key feature of the fog/mist bays is that we now have the ability to alter the misting frequency of each bay independently, giving us the option of weaning in-situ, rather than moving the whole bay into a drier area to wean, which is labour intensive. Our computerised misting system also allows us to set up a weaning programme. Plants can be weaned over any period of time by setting the programme to gradually decrease the misting frequency over a period of a week, two weeks, a month or whatever is required. This gradual weaning off reduces the stress to the cuttings and losses from weaning are a thing of the past.

“The computer system is really the hub of the unit and we believe it is unique in the UK. It is rigged up to a number of sensors measuring light, temperature and relative humidity, to calculate the vapour pressure deficit.

“Energy screens are also a feature of the new unit, to conserve heat and for shading. “We did our homework and got out and about before finalising our plans, visiting different growers to see what was available and glean knowledge from their experience,” says Geoff.

Energy saving shade screens being pulled over a crop

Currently, transport and handling evolves around Danish trolleys but there are plans to install conveyors to ease and speed the movement of plant material. “We designed the layout of the block so it has a logical flow to it,” continues Geoff, “starting with the work area where we prepare material, leading to the propagation compartment and weaning zones, then through to the growing on beds, where we have a mix of rooted plugs and 8 cm liners.

“Water is disinfected using chlorine dioxide, which helps to keep fog/mist nozzles free of algae; we’ve also found it helps control various leaf-spot problems on crops like *Hebe*, *Hedera*, *Lavandula* and *Viburnum tinus*,” adds Geoff, “and we use Jet 5 to disinfect our paths and beds as we place a big emphasis on maintaining good nursery hygiene, especially in our propagation areas.”

The length of time required for propagation will vary with subject, timing and available facilities, for example, cuttings propagated using basal heat usually root quicker than those without.

There is also a need to be aware of how long cuttings and seeds will occupy propagation space in order to plan throughputs and make the best use of resources; this underlines the need to propagate material when it is in the optimum condition for rapid throughput.

Table 2. Example calculation to determine cutting numbers required

Stage	% losses	Plants remaining
Total plants required	100	1,000
Losses during rooting	10	900
Losses during establishment	10	810
Other losses	10	729
Unsaleable	10	656

When calculating the number of plants to propagate, the following factors need to be considered:

- Final total of plant numbers required (use sales data and market information)
- Germination or rooting percentage
- Establishment losses during propagation
- Losses due to pests, diseases or other cultural issues
- Wastage (unsaleable or poor quality plants)

10 cuttings are required to obtain 6.56 rooted plugs or liners. Therefore, the total number of cuttings required for 1,000 rooted plugs or liners is 1,525 (1,000 divided by 6.56 x 10) as shown in Table 2.

Record-keeping

Successful propagation requires disciplined record-keeping and attention to detail. Some form of diary or record sheet is a useful reference point, particularly for future planning and when studying the case histories of particular crops, especially when diagnosing losses or seeking a better understanding of successes.

Figures 1, 2 and 3 show example propagation and weaning record sheets, while Figure 4 shows an example propagation best practice sheet devised by a leading nursery for staff training, quality control and monitoring purposes. Each of these examples can be developed and adapted.

Table 3 (overleaf) shows an example of an annual propagation programme suitable for nurseries able to employ a wide range of resources but which can also be adapted for those with more limited facilities, systems or requirements.

Plant name..

Propagation method..

Propagation date _ _ /_ _ /_ _ _ _ **Potting date** _ _ /_ _ /_ _ _ _ **Sales date** _ _ /_ _ /_ _ _ _

	Planned	Actual
Sales requirement (finished plants)		
Losses during rooting		
Losses during establishment		
Other losses		
Unsaleable		
Cuttings required		

Location..

Propagation space required (m^2)..

Growing on area required (liners/plugs)..

	Planned	Actual
Propagation date (week number) Propagation source Labour required (man hours/days) Personnel involved		
Comments		

Figure 1. Example propagation record sheet

Batch number	Plant name	Sales target	Propagation target	Target week	Week ready	Week taken	Quality score	Uniformity score	Disease free (Y/N)	Pest free (Y/N)	Actual propagation quantity	Shortfall	Date	Signed off
													_ _/_ _/_ _ _ _	
													_ _/_ _/_ _ _ _	
													_ _/_ _/_ _ _ _	

Figure 2. Example propagation check sheet
(Quality and uniformity scores: Poor = 1, Acceptable = 2, Good = 3, Excellent = 4)

Batch number	Week started	Block weaned (Y/N)	Percentage weaned	Quality	Uniformity	Date	Signed off
						_ _/_ _/_ _ _ _	
						_ _/_ _/_ _ _ _	
						_ _/_ _/_ _ _ _	
Comments:							

Figure 3. Example weaning check sheet

Cutting source	Stock plants and nursery crops
Location of cutting preparation	Propagation unit
Ripeness of wood	Softwood cuttings
Rooting medium and tray	Fertis 84/100
Preferred tools	Red snips
Type of cutting	Nodal tip
Rooting hormone	Chryzopon Rose (0.1% IBA)
PPE required	None required
Propagation environment	White plastic
Prone to	*Botrytis* when in flower
Rooting requirements	Remove flowers, otherwise won’t root well
Weaning requirements	48 hours under fleece
Other notes	

Work rates	2010		2011		2012	
	Target	Actual	Target	Actual	Target	Actual
Collection of cuttings						
Preparation/insertion						
Grade/wean trays						

Figure 4. Example best practice record sheet for staff training, monitoring and quality control (Abelia x grandiflora)

Table 3. Example of an annual propagation programme

Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seed under glass		□	■	■	■	□	□	□	□	□	□	
Seed outdoors		□	□	■	■				□	□	□	
Micropropagation	■	■	■	■	■	■	■	■	■	■	■	■
Softwood cuttings		□	■	■	■	□						
Semi-ripe cuttings (deciduous)					□	■	■	■	■			
Semi-ripe cuttings (evergreens and conifers)	■	■	■	■	□	□	□	■	■	■	■	■
Leaf-bud cuttings	■	■	■	■	□	□	□	■	■	■	■	■
Hardwood cuttings	■	■	■	□						□	■	■
Root cuttings	■	■	■	□						□	■	■
Division	■	■	■	■	□	□	□				■	■
Layering and stooling		□	■	■	■	■	□					
Budding						■	■	■	□			
Bench grafting	■	■	■	■	■	■	■	■	□			
Field grafting		■	■	□								

■ Optimum periods □ Other potential periods

It is not anticipated that nurseries will use all of these techniques, rather a selection depending on crops and resources.

Stock plants

Many easy rooting HNS subjects can be readily propagated from nursery crops, provided they are healthy. Dedicated stock plants, however, enable growers to exercise quality control from the start of the production process and are especially useful for slow growing or difficult to root subjects, for which nursery crops may be unable to provide sufficient material of the requisite quality at the optimum time.

While stock plants may be costly to have and maintain, most propagators use them for at least some of their requirements. They offer security of supply and enable crops to be propagated at specific times within a schedule and when in optimum condition; container-grown mother plants forced under protection for early season cuttings are an example of this.

HRI Efford (formerly known as Efford Experimental Horticulture Station) undertook a considerable programme of research into stock plant management and quickly demonstrated several advantages, notably the ability to collect cutting material at the optimum time for propagation and a marked improvement in the uniformity of growth within batches of plants. A disciplined management programme, which included nutrition, irrigation, crop protection and pruning to manipulate growth, also provided even flushes of growth, enabling easy selection of uniform, graded material.

Well-managed stock plants

All of the HRI Efford stock was clonal in origin, selected for trueness to type and propagated from selected mother plants.

Pruning techniques and the preconditioning of cutting material (by etiolation or partial blanching using blackouts placed over stock plants early in the season or by wrapping stem sections with black tape to exclude light) to improve rooting of difficult species featured in a complementary programme of work at NIAB East Malling Research (NIAB EMR).

The management and manipulation of stock plants for the production of leafy cuttings was also considered in an AHDB Horticulture/Defra-funded programme of work undertaken at NIAB EMR devised to provide HNS growers with a better understanding of how to control growth and optimise cutting production.

Practical aspects of stock plant management

A well-managed stock bed area provides nurseries with high-quality, well-graded cuttings that are an essential part of the production process. They also crucially provide security of supply at the optimum time for propagation.

Well-managed stock plants provide propagation material of known health status and should be free from pests and diseases, including virus infection. Weeds can also be kept under close control, while nutrition and pruning can be focused and carefully managed.

Field-grown stock plants are an especially useful source of clean cutting material for crops regularly troubled by leaf spot diseases such as *Berberis, Camellia, Hebe* and evergreen *Prunus*, which tend to be more prevalent among container-grown plants, especially where irrigated overhead.

High-quality plants that are clonal in origin, true to type, propagate well and are of known health status, provide the best and most reliable stock plants and, in turn, high-quality propagation material.

When selecting clones, ensure they are correctly named and labelled, of good form and high rooting potential. Keep a note of the donor or source of each plant, batch or block for future reference.

As a general guide, the number of stock plants required should be based on average yields of 25 cuttings per plant during the second year of establishment, rising to 50 cuttings per plant in year three, 100 cuttings per plant in year four and 150 cuttings per plant from year five onwards. Research at HRI Efford established that yields may be higher, especially if several grades of cuttings are taken over time. Allow a two to three-year establishment period before harvesting propagation material regularly.

Stock beds should be located near to the propagation area to save time; cutting material should spend as little time in transit as possible, particularly soft, summer cutting material.

Choose a well-sheltered site with windbreaks, if necessary, and fence against rabbits and deer.

Avoid frost pockets and heavily shaded areas with poor light levels.

Select a well-drained but moisture retentive medium loam soil with a neutral pH (6.5 to 7.0) that will accommodate most species. Ericaceous or calcifuge subjects such as *Camellia, Crinodendron, Enkianthus, Hamamelis, Hibiscus, Magnolia* and *Skimmia* require a low pH soil (4.5 to 5.5), as do most conifers and heathers. Undertake soil analyses prior to planting and apply base dressings accordingly. Top-dress with a fertiliser in early spring.

Field-grown stock plants

Alpines, heathers and other low growing subjects should be planted on raised beds to aid winter drainage and reduce soil splash onto foliage, which can spread diseases, notably *Rhizoctonia*, a common problem on heathers.

Plants growing on raised beds

Soil-grown plants can also be housed under protection via mobile shade tunnels in field situations to provide further flexibility.

Keep a record and sketch a plan of what is planted, and where and when for future reference. This also saves time, particularly when harvesting cuttings on larger sites.

Allow enough space between the plants and the rows to enable easy access and management. With slow growing species such as *Camellia* and *Rhododendron,* which produce fewer cuttings, plant double the number required to provide increased numbers of cuttings early on, before removing alternate plants as growth increases. Table 4 can be used as a guide when deciding on stock plant spacing.

Table 4. Stock plant spacing

Vigour	In row spacing (m)	Between row spacing (m)
Slow growing (e.g. *Camellia*)	0.6–0.9	0.9–1.2
Medium (e.g. *Berberis*)	0.9–1.2	1.2–1.8
Fast (e.g. *Buddleia*)	1.2–1.8	1.8–3.0

Space alpines, heathers and other low growing subjects, including some herbaceous perennials at 0.45 m x 0.45 m or 0.6 m x 0.6 m depending on vigour.

High numbers of stock plants can be grown well in relatively small areas, for example, with stock plant hedges spaced 3 m apart and 45 cm in the row, 6,500 stock plants can be grown per hectare although additional land will be required to accommodate replacement plantings to ensure continuity of supply.

Stock plant husbandry

A summary of the month-by-month cultural requirements of HNS stock beds can be found in Table 5 at the end of this section.

Soil preparation

Prepare soils thoroughly and well in advance of planting, using bulky organic manures to boost fertility and improve structure. Avoid sites known to have a history of soil-borne diseases such as *Phytophthora* species or *Verticillium dahliae*. Checks should also be carried out for root invading nematodes such as *Pratylenchus* species and *Xiphinema* species.

Weed control

Perennial weeds including brambles, bindweeds, couchgrass and thistle should be dealt with well in advance of planting. Use permeable ground cover fabrics or mulches for safe and effective weed control around stock plants, particularly while they establish. Early work at HRI Efford with polyethylene mulches found that cutting quality during drought periods did suffer without irrigation, and subsequent plantings had low-level watering systems installed underneath the mulch.

Residual herbicides can be considered once stock plants are established but should be used with care; very soluble products may cause damage, check growth or possibly reduce the rooting potential of cutting material.

Crop protection

Stock plants should be grown like other commercial crops, monitor them regularly for pest or disease problems. Use integrated crop management techniques including biological pest control where practical, to reduce pesticide inputs.

Irrigation

Irrigate stock plants during dry periods and, for best results, at least 24 hours before removing cutting material. Good rooting requires cutting material to be cool, fresh and turgid; similar remarks apply with bud wood. Subjects such as deciduous *Azalea* and *Ilex* are especially sensitive to drought, which reduces extension growth and cutting quality. Mulches can also be used to conserve soil moisture.

Nutrition

Maintain the nutritional status of the stock plants with regular fertiliser top-dressings but don't over-do this; an excess of nitrogen, for example, will produce very soft, lush growth unsuitable for propagation. For this reason, very soft tip growth is usually discarded when preparing summer cuttings.

As a general guide, field-grown stock plants should be top-dressed with a 2:1:1 fertiliser annually each spring, augmented by the outcome of soil analyses every three years. However, account should be taken of the differing requirements of slow growing conifers, salt sensitive ericaceous subjects and quick growing, more vigorous subjects.

Container-grown stock plants should be monitored more frequently, with growing media analyses undertaken each spring and supplementary nutrition provided as required to maintain vigour. Plants will also require repotting into fresh growing media or potting-on into larger pots, periodically depending upon plant vigour.

Stock plants should also be liquid or foliar fed, for example, using a 1:2:1 fertiliser during periods of active growth to maintain quality and boost phosphate levels ahead of cuttings propagation. Routine micro-feeding of stock plants with compost teas will provide supplementary nutrition.

Little detailed work appears to have been done on the nutritional requirements of stock plants and, in particular, the merits of using supplementary feeding to improve the rooting potential of cuttings.

Shading

Work at HRI Efford found that shading significantly improved the quality of growth and cutting material of many HNS subjects, notably *Azalea, Camellia, Eucryphia, Magnolia, Pieris, Rhododendron* and *Skimmia.* Other subjects that respond well include ferns and various herbaceous perennials, such as *Anemone x hybrida, Epimedium, Heuchera, Hosta* and *Pulmonaria*. In more exposed areas, fuller protection may be required for evergreen subjects in winter.

Shading heather stock plants during the spring and summer period reduces flower initiation and increases the number of cuttings per plant.

Shade provision over evergreen stock plants

Grouping plants together

Plants with similar cultural requirements should be grouped together, for example, deciduous stock, evergreen stock, conifers, climbers, etc. This enables their cultural requirements to be considered more fully and eases the harvesting of cuttings, as material within each block should be ready over a similar time period.

Growing stock plants under protection

Work at HRI Efford examined different forms of protection to manipulate stock and provide greater management flexibility, as well as improved cutting quality. Short term polyethylene covers were used successfully to accelerate cutting production of *Hydrangea* with plants being covered during April and May while *Acer, Magnolia* and deciduous *Azalea* were grown in walk-in tunnels.

Shade structures also gave marked improvement in quality for several high-value subjects needing protection from bright summer sun, including: *Acer, Azalea, Camellia, Mahonia, Photinia, Pieris* and *Rhododendron.*

Stock plants grown under protection

Glasshouse structures can be used to force high-value stock grown in containers. Growing such plants in containers enables them to be moved outside for a resting period, although production in this way is short term and usually restricted to a cycle of two or three years.

Artificial lighting can be used to advance the growth of stock plants, for example, *Clematis,* to enable the rooting season to be extended and a greater number of cuttings to be harvested from each plant.

Pruning

Research has shown that pruning is an essential part of good stock plant management. It influences cutting yield, quality, rooting potential and timeliness and this can be exploited to aid crop scheduling, raise productivity and improve cutting quality. The use of different pruning techniques enables the number, timing and quality of cuttings produced to be managed, although the optimum pruning technique varies with subject and objective.

At HRI Efford, pruning was regarded as one of the most important annual management tasks to maintain juvenility for enhanced rooting, increase cutting numbers, initiate a predictable 'flush' of material of optimum size and condition and shape plants to enable easy access and harvesting. Juvenile plant material usually propagates more readily than mature wood, especially in terms of cuttings, largely due to it having greater carbohydrate reserves and fewer lignified cells in primary tissues.

To maximise cutting yield, stock plants should be pruned lightly during early spring prior to growth, harvesting the cuttings during June. The process of cutting removal will also stimulate further growth flushes that can be harvested during July and August. A later harvest may also be possible but cutting quality and, in turn, rooting potential may decrease.

Hard pruning of stock plants in early spring, by removing a third to a half of the original framework will reduce the cutting yield, but the cuttings generated will be larger and stronger. In general, such cuttings root and establish better later in the season than cuttings taken from lightly pruned stock plant hedges, especially in the case of more difficult to root subjects like *Garrya elliptica.*

Work undertaken at HRI Efford indicated that *Hydrangea, Hypericum, Potentilla, Senecio* and *Syringa* responded well to stooling while *Deutzia, Forsythia, Philadelphus* and *Weigela* should be pruned back by at least half each year.

Deciduous *Azalea* and *Viburnum* should be pruned back by about a quarter only. *Ilex aquifolium* responds well to light pruning regimes, supplemented periodically with renewal pruning, during which a proportion of the older wood is removed to maintain juvenility and vigour. *Camellia* and *Viburnum x bodnantense* also respond well to the periodic removal of older wood undertaken on a three-year cycle. Most conifers respond well to light pruning or trimming; for many cultivars, the removal of cutting material suffices without the need for further formative pruning.

To maximise cutting production throughout a season, the removal of 50–80% of the previous year's wood consistently gave the best results with a range of subjects at NIAB EMR. Such pruning also enabled batch production of cuttings to be undertaken, with up to three separate harvests being feasible. Research at NIAB EMR found the extent to which flowering wood is removed is critical; in early summer, flowering subjects like *Philadelphus* and *Weigela*, pruning should be sufficient to remove flower buds, otherwise subsequent shoot production will be poor.

Work at NIAB EMR found that response differences to pruning regimes also persisted for quite some time with cutting numbers still being greater from lightly pruned stock plants compared with those that were hard pruned, some 15 months later. Cutting yield in the second year after pruning was not significantly affected by heavy harvesting of cuttings in the previous year. In the case of *Garrya* and *Philadelphus,* for example, yield actually increased.

Older stock plants can sometimes be regenerated by hard pruning or 'stooling', usually in February and March, cultivars of *Cornus, Malus* and *Salix* often respond well to such treatment. However, severe pruning regimes often delay the production of cuttings in slow growing subjects such as *Viburnum carlesii* 'Aurora' by up to four weeks, with an attendant fall-off in rooting potential later in the season.

The timing of pruning work is important and varies with subject. At NIAB EMR, subjects such as *Forsythia x intermedia* 'Lynwood' LA79 and *Garrya elliptica* 'James Roof' responded better to early pruning (March), in contrast to *Philadelphus* 'Virginal' LA83 where pruning in May yielded most cuttings. At HRI Efford, the work was usually done in April, with the severity of pruning largely dependent on species. However, stooling was usually done during February and early March.

Commercially, annual pruning is usually done in late winter or early spring to maintain juvenility and so improve the yield, rooting potential and growth potential of cuttings; as such, it is an essential part of good stock plant management.

Container stock plants of quick growing crops under protection may be trimmed several times during the season as cuttings are removed, for example: *Abelia, Ceanothus, Choisya, Cistus, Clematis, Fuchsia, Hebe, Hydrangea, Jasminum, Lonicera, Pieris, Senecio* and *Spiraea.*

Herbaceous stock is usually cut back during the dormant autumn and winter period, when division may also be undertaken, for example, with *Aster, Astilbe, Geranium, Hosta, Helenium, Heuchera* and *Rudbeckia.* With *Nepeta*, if plants are cut back when flowering, they will produce a flush of vegetative basal shoots for propagation that root well.

Alpines, heathers and herbs can be pruned or clipped back when cuttings are removed for propagation, usually throughout the summer months or after flowering.

Preconditioning

In this context, the term preconditioning refers to the etiolation or partial blanching of cutting material to improve its rooting potential. Cold storage to delay cutting material and forcing stock plants under protection to advance material availability are other recognised preconditioning techniques.

Essentially, the dark preconditioning of shoots prior to cutting removal raises the level of endogenous auxin, the naturally occurring plant hormone that stimulates root initiation, thereby helping to improve percentage rooting, root quality, speed of weaning and subsequent growth.

Preconditioning is undertaken to increase the rooting potential of cuttings taken from difficult to root subjects. This technique can be used for recalcitrant species, initially on a trial basis to build confidence. Dark preconditioning can also improve root quality, speed of weaning and subsequent liner growth. At NIAB EMR, *Corylus avellana* 'Aurea' plants, for example, reached 0.5 m by the autumn of the propagation year when grown under protection, while cultivars of *Syringa* comfortably exceeded this height within a year from propagation.

Established stock plant hedges are covered with ventilated black polythene clad frames prior to cutting collection in spring or early summer. Alternatively, container plants can be palletised and moved into a dark room or tunnel to precondition shoots.

Research at NIAB EMR (AHDB Horticulture project HNS 41: ***Stock plant management and reconditioning)*** found that dark preconditioning plants during late May and then propagating from these three to four weeks later, following weaning the plants back into 50% light, raised the rooting ability of difficult subjects, and led to better root quality, improved speed of weaning and liner throughput.

Container-grown stock plants also respond well to preconditioning and, while cutting numbers may be fewer than with stronger field-grown plants, they offer greater flexibility in terms of forcing (under glass) or delaying (using cold storage) cutting production.

Wrapping stem sections with black tape to exclude light is another way to dark precondition shoots and has been shown to improve the rooting of 'difficult' species such as M9 rootstocks for field-working and cultivars of *Syringa*.

Preconditioning stock plants using darkness for a two-week period in spring to early summer is unlikely to reduce cutting yield in the propagation year, or stock plant vigour.

Cutting storage

Cutting material should be labelled and stored in shallow trays, boxes or white polythene or hessian bags to keep them cool; cold stores are ideal and remove field heat. As a guide, around 3°C and 90% relative humidity will suffice for most subjects. Material should be used quickly and long-term storage avoided.

Container-grown stock plants

Container-grown stock plants give flexibility and can be forced under protection for early cutting material or preconditioned to improve rooting. Subjects such as *Azalea* (deciduous), *Cotinus, Exochorda, Magnolia* and *Syringa* root well from soft, juvenile cutting material taken early in the season.

Supplementary lighting can also be used with stock plants under protection to extend the period over which cuttings are available and to increase cutting yield.

Container growing is useful for alpines, heathers and many herbaceous perennials and associated subjects propagated from cuttings throughout spring and summer such as *Aster, Astrantia, Campanula lactiflora/latiloba, Delphinium, Penstemon* and *Salvia nemorosa.* Cultivars of bearded *Iris* and *Hemerocallis* can also be propagated from summer divisions, for which stock plants are especially useful, due to the large quantities of material required. Alpines and heathers grown through 9 cm to 3 litre pots over a three-year timeframe make ideal stock plants for scheduled production.

Alpines grown in 3-litre pots make ideal stock plants

Container-grown stock plants also permit batch or scheduled production of HNS subjects requiring timely and sequential supplies of uniform cuttings.

Stock plants for root cuttings

For propagation using root cuttings, young stock plants either grown in containers or the open ground provide the best propagation material, the former obviating the time-consuming task of lifting from the field prior to removing root material for cuttings.

The use of peat-based growing media with container-grown stock plants also promotes the development of young, fibrous, actively growing root material ideal for propagation.

If field-grown stock plants are preferred, bulky organic matter should be incorporated as soil conditioning prior to planting to help promote active root development. Irrigation is essential in dry summer weather to promote maximum root growth.

Field-grown stock plants should be lifted from the ground and the soil gently shaken away from the roots to enable suitable root material to be selected and removed.

With large field-grown plants that cannot be lifted, the soil should be scraped away to expose the roots for use and collection, after which the soil should be returned and firmed promptly to prevent drying out.

Large, established container-grown plants can be handled likewise once removed from the pots or, in the case of younger plants, root cutting material can be removed when the growing medium has been gently shaken away to expose young roots.

Stock plants for layering and stooling

High-quality stock plants grown on well-drained, fertile land with a sheltered aspect, free of perennial weeds, are essential to produce the requisite succession of strong, young shoots suitable for layering and stooling. In the case of layering, plants should be well established and widely spaced, usually some 2–2.5 m, in rows set 3 m apart, to enable the necessary pegging down of shoots.

Given the long-term nature of stool beds, only high-quality stock plants of known health status should be used. In-row spacing varies with the vigour of the species grown and the number of shoots produced by a particular subject when in full production but will generally be around 25–40 cm. Typically, rows are spaced at 1 m to facilitate earthing up.

Stock bed production periods

The productive life of a stock bed is usually 10–15 years (with regular pruning), depending on species and how well or otherwise it has been looked after. Some tree species including *Malus, Platanus, Prunus, Quercus* and *Tilia* produce juvenile material for longer if pruned regularly, while heather or alpine stock plants may need replacing every three to five years.

Begin renewal plantings at least three years in advance of stock replacement to ensure continuity of supply. Container-grown stock plants are usually kept for one or two seasons, perhaps longer with supplementary nutrition, before being grown on as saleable specimen plants.

Table 5. Example management programme for HNS stock beds

Month	Planting	Pruning	Crop protection	Cultural	Harvesting
January	Conifers, evergreens and deciduous species	Fruit and ornamental HNS for bud wood production and hardwood cuttings	Review and update spray programmes for pest and disease control Check stock plants under protection for *Botrytis*	Review and update planting plan	Root cuttings (herbaceous) Hardwood cuttings (shrubs, fruit stocks and HNS) Semi-ripe cuttings (conifers) Softwood cuttings from forced stock plants under protection (deciduous and evergreen shrubs) Scion wood for bench grafting (e.g. *Betula, Carpinus)*
February	Conifers, evergreens, roses and deciduous species	Fruit and ornamental HNS for bud wood production for hardwood cuttings	Review and update spray programmes for pest and disease control Check stock plants under protection for *Botrytis*	Check labels, tree ties and stakes	Root cuttings (herbaceous) Hardwood cuttings (fruit stocks and HNS) Semi-ripe cuttings (conifers) Softwood cuttings from forced stock plants under protection (deciduous and evergreen shrubs) Scion wood for bench grafting (e.g. *Betula, Carpinus)*
March	Conifers, evergreens, roses and deciduous species Herbaceous perennials	Stool stock beds (e.g. *Cornus, Hydrangea, Hypericum, Potentilla, Salix, Senecio, Spiraea* and *Syringa*) Prune *Berberis, Buddleia, Deutzia, Forsythia, Philadelphus, Weigela* and similar Renewal prune as required (e.g. *Camellia, Viburnum* and *Ilex*) Prune heathers Prune stock hedges for hardwood cutting production (shrubs and trees)	Apply residual herbicides from March onwards for spring and summer weed control on established stock beds only Check and treat *Malus* for scab Check and treat all stock for aphids, March onwards	Apply fertiliser top-dressing (undertake soil analyses every three years)	Scion wood for field grafting (deciduous shrubs and trees) Semi-ripe cuttings (conifers) Softwood cuttings from forced stock plants under protection (deciduous and evergreen shrubs) Leaf-bud cuttings (e.g. *Camellia, Mahonia* etc.) Root cuttings (herbaceous) Herbaceous basal cuttings Early softwood cuttings forced under protection Scion wood for bench grafting (conifers) Seed harvesting, March onwards

Table 5. Example management programme for HNS stock beds (continued)

Month	Planting	Pruning	Crop protection	Cultural	Harvesting
April	Conifers, evergreens and deciduous species Herbaceous perennials	Broad-leaf evergreens for cutting production	Check and treat for two-spotted spider mites, April onwards, particularly under protection (e.g. *Buddleia, Crinodendron, Choisya* and *Euonymus*) Check/treat for caterpillar damage, April onwards (e.g. *Choisya, Euonymus, Photinia*, conifers)	Use irrigation to maintain vigour during dry periods from April onwards for stool beds and layer beds Mulch application for spring weed control	Softwood cuttings (e.g. *Acer, Azalea, Cotinus, Exochorda, Hypericum, Magnolia, Spiraea, Syringa*), ideally propagated in fog with basal heat Herbaceous basal cuttings
May	Herbaceous perennials, complete planting	Broad-leaf evergreens for cutting production	As April Check and treat for powdery mildew (e.g. *Euonymus, Hydrangea, Lonicera, Malus, Photinia, Pyrus, Rhododendron*, roses and herbaceous plants) Check for conifer spinning mite (e.g. Junipers)	Shade as required from May onwards (e.g. *Camellia, Pieris and Rhododendron*) Irrigate as necessary	Softwood cuttings continued including direct stuck Buddleia under mobile covers Heathers, herbaceous and alpine tip cuttings
June		Light prune as necessary, *Berberis*, *Potentilla* and *Viburnum* Summer prune or trim conifers	Continue routine checks and treatments for aphids, caterpillars, capsid bug, two-spotted spider mite, etc. throughout the summer months Continue checks and sprays for powdery mildew throughout summer	Mulch application for summer weed control Irrigate as necessary Shade as necessary	Softwood and semi-ripe cuttings including sun tunnel propagation Heathers, herbaceous and alpine tip cuttings Bud wood for chip budding
July			As for June Spot spray weeds	Irrigate as necessary Shade as necessary	Bud wood for chip budding and bench grafting (e.g. *Hamamelis, Rosa*) Semi-ripe cuttings including sun tunnel propagation

Table 5. Example management programme for HNS stock beds (continued)

Month	Planting	Pruning	Crop protection	Cultural	Harvesting
August			As for July		Semi-ripe cuttings including evergreen *Azalea, Elaeagnus, Garrya* and *Pyracantha* Divide bearded *Iris* and *Papaver*
September	Conifers and broad-leaf evergreens Lift, divide and transplant herbaceous (starting with *Paeonia*)		As for August		Semi-ripe cuttings including evergreen *Azalea*, *Elaeagnus*, *Garrya* and *Pyracantha* Harvest and sow herbaceous seed, (e.g. *Helleborus*)
October	Conifers and broad-leaf evergreens Lift, divide and transplant herbaceous		Check stock plants under protection for *Botrytis* Top up residual herbicides (established stock only)		Semi-ripe cuttings including conifers Start mini-divisions (herbaceous)
November	Conifers, evergreens and deciduous species Lift, divide and transplant herbaceous		Check stock plants under protection for *Botrytis* Top up residual herbicides (established stock only)		Semi-ripe cuttings including conifers Hardwood cuttings (fruit and HNS) Root cuttings (herbaceous)
December	Conifers, evergreens and deciduous species		Review and update spray programmes		Hardwood cuttings (fruit and HNS) Root cuttings (herbaceous)

Clonal selection and plant health

Variability in rooting, growth and flowering characteristics between different clones (the vegetatively produced progeny of a single plant) of a particular plant is a common problem in HNS production. It influences propagation performance and, ultimately, saleability, particularly where clones are highly variable and not true to type. For this reason, superior clones are often selected from stock and bulked up to provide a reliable source of propagation material that is true to type.

HNS clonal selection scheme

Variation within HNS formed the backdrop to a hardy ornamentals scheme that began in 1976 at the former Long Ashton Research Station, progressed to NIAB EMR (1984) and ceased in 1991 at HRI Efford. Of particular concern was that the same HNS subjects supplied by different nurseries performed differently, depending upon the source.

The principal objectives of the scheme were to:

- Examine the causes of variability
- Assess, identify and select a clone or clones that were true to type, reliable in performance and, if possible, an improvement on those in commercial practice at the time
- Identify plants showing novel and interesting variation that would be of value in maintaining genetic diversity within the species or cultivar

Three main causes of variability were identified: incorrect naming, genetic variation and infection by viruses or other disease pathogens. During the course of the scheme, many superior clones were identified and released to the industry. Some of these, denoted by the EM or LA suffix, still exist and are worth sourcing for stock plants.

Dutch Plant Health and Inspection Service (NAKTUINBOUW formerly NAKB)

This scheme was derived from a gradual merger of several plant health inspection services, including the former Inspection Service for Arboriculture (NAKB, established in 1943) and 'Nederlandse Algemene Keuringsdienst voor Bloemisterij-en Boomkwekerijgewassen' – Inspection Service for Floriculture and Arboriculture (NAKTUINBOUW) which is a foundation run under the auspices of the Dutch Ministry of Agriculture.

The scheme functions along similar lines to the former Nuclear Stock Association (NSA) in the UK and its principal remit is to promote and facilitate the growing of healthy, high-quality true to type plant material. Its inspection work covers top and soft fruit species (most notably, *Malus* and *Prunus*) and ornamental trees (including: *Acer, Betula, Crataegus, Fagus, Fraxinus, Tilia* and *Quercus*) and conifers (particularly, those grown in the Netherlands for timber production).

Nursery inspections for approval and certification cover administration, plant production, plant management and phytosanitation, and include stock plant material, nursery propagation material and plants grown on for sale. Successful nurseries can use the NAKTUINBOUW quality inspection mark on their material.

The scheme fosters close links between the Dutch Plant Health Service and the research expertise at Wageningen, from where virus-free and tested clonal material is derived. This material is propagated and maintained by NAKTUINBOUW and each year new virus-free stock is added to the collection.

Ensuring growers have access to healthy plant material that is true to type is one of the principal aims of the inspection service and, in order to facilitate this, the organisation manages its own stock plant material, which is sold to growers on demand. UK growers often source NAKTUINBOUW certificated material for plant propagation, particularly bud and scion wood for fruit and ornamental tree propagation.

Rootstocks

Rootstocks, onto which a bud or scion is grafted or budded to form the head or main branch framework of the tree are commonly used in nursery stock production. With ornamental subjects, this will usually be because of their greater vigour or rooting potential although, with fruit tree propagation, it can also be on account of their growth control characteristics, as in the case of dwarfing rootstocks required for the production of smaller, more compact trees suitable for retail sales.

Seedling rootstocks

Rootstocks grown for the production of woody ornamentals, can be raised successfully and economically from seed, normally drilled in outdoor seed beds to produce one or two-year seedlings for budding or grafting onto. While relatively cheap, the main drawback of seedling rootstocks is their inherent variability, leading to uneven growth following budding or grafting. Hence, only strong, high-quality rootstocks grown from reliable seed sources of known health status and provenance should be used.

Clonal rootstocks

Clonal rootstocks are propagated vegetatively, usually from hardwood cuttings and, while more costly to produce than seed raised material, have the advantage of greater uniformity, provided that evenly graded, good quality propagation material taken from clonal stock plants is used.

Fruit tree rootstocks for budding or grafting are usually propagated by hardwood cuttings during the winter period when they are leafless and dormant, although they can also be raised from stool beds and layering.

Micropropagation

Micropropagation can be used for raising rootstock material, usually in respect of subjects that are difficult or slow to root by conventional means or where rapid bulking up is required.

Stooling

The underlying principle of this technique is that when young shoots are placed in darkness, for example, by having soil earthed up over part of them, they become blanched and produce young, adventitious roots, at which point they are harvested from the mother plant and grown on for budding or grafting or to form young nursery trees. It differs from etiolation, whereby shoots are actually grown in darkness.

While probably the oldest form of vegetative propagation and one of the most reliable, the labour-intensive nature of stool bed management has led to it being superseded by other, more cost-effective techniques for propagation of rootstocks.

Layering

Rootstocks, particularly those intended for fruit tree production can also be propagated by a form of layering known as etiolation layering, whereby young mother plants are planted at an angle of 45°, pegged down and covered with fine soil before bud break such that young lateral shoots are produced in darkness and become etiolated. The emerged shoots are then 'earthed up' two or three times, starting in late spring before the rooted shoots are harvested during the winter, lined out and grown on for budding or field grafting. Unrooted shoots are pegged down again to produce rootstock material for the following year.

Once favoured for the production of cherry rootstocks and, occasionally, walnut and mulberry plants, this system is also labour intensive and difficult to mechanise, and no longer economic on a commercial scale.

Other types of layering are still practiced for the raising of a range of woody ornamental subjects.

Collection and storage of vegetative propagation material

Collection

The collection of cuttings and graftwood should be done in a carefully coordinated and structured way so as to link efficiently with subsequent storage, preparation and insertion. Collected material should not be left unattended otherwise it will quickly deteriorate.

There are some basic, but important, rules to follow with bags and labels used for the collection and storage of propagation material, notably:

- Use strong, white polythene bags or hessian sacks when collecting cuttings. Avoid using clear or black polythene bags as they absorb more heat and the cuttings will quickly deteriorate, especially in summer
- Dampen the bags lightly with plain water on the inside to help keep cutting material moist and turgid, especially in spring to summer. Don't overdo this, otherwise soft cutting material will quickly rot
- Ensure each bag is clearly labelled using a waterproof marker pen
- Write clearly and ensure the material is correctly labelled, with the name of the plant, the date collected and the source of the material
- Ensure the labels are strong, waterproof and clearly visible and, in the case of tie-on labels, are well secured to the bag
- Ensure the labels follow the propagation material through the preparation and insertion stages so the plant material can be quickly and correctly identified
- Once inserted, use plastic, stick in labels with each tray or batch of cuttings or seed; write the full name of the subject on the label, the source and the date of insertion

Generally, cuttings taken from strong, juvenile, actively growing shoots will root quicker and better and produce stronger finished plants than material taken from less active shoots. Very soft growing points with high nitrogen levels are less likely to root well.

In work at NIAB EMR, the timing and frequency of harvesting affected cutting productivity. Early season harvesting (early June) and repeat harvesting as new shoots reached the requisite size led to a greater number of cuttings compared to leaving cutting material on the stock plants until later (late July or mid-September). The early season removal of cutting material often stimulated new shoot growth that could be harvested later.

When collecting cutting material in the field, the removal of branches or larger shoots from stock plants and the subsequent preparation of cuttings from these on return to the propagation area is usually more efficient than removing large numbers of small cuttings at source.

Removing larger shoots from stock plants and preparing cuttings from these is efficient and helps keep soft material fresh

Spring and summer cutting material should be collected in the early morning when conditions are cool and fresh. It should be kept out of direct sunlight and transferred to cold storage promptly. Soaking cuttings or cutting material in water for prolonged periods in an effort to keep them fresh is not advisable, as such material can quickly deteriorate; controlled temperature storage is much better.

While less perishable than softwood and semi-ripe cutting material, the collection and handling of hardwood cuttings should be undertaken in a similar way, in that the material should be bagged and dealt with promptly and kept away from direct sunlight or heat and extremes of moisture.

Storage

When handling propagation material, especially softwood summer cuttings, which can deteriorate quickly, the emphasis must always be on working quickly and efficiently, to keep material in optimum condition.

Water loss from unrooted leafy cuttings must be minimised so they remain fresh, turgid and in optimum condition for rooting. Material should be handled quickly and kept in a cool, shaded location away from direct sunlight. Material should also be handled carefully as damaged tissue may become an infection site for disease, notably *Botrytis*; soft cuttings especially are easily bruised.

Plastic boxes lined with thin gauge white polythene can be used to keep cutting material cool and moist.

Plastic boxes lined with thin gauge white polythene keep cutting material cool and moist

Cold temperature storage to remove 'field heat' from soft leafy cutting material maintains cutting quality and improves rooting potential. Usually, two hours storage at 1–3°C following collection will restore turgidity and ensure cuttings are fresh before insertion, although most species can be stored in this way for several days. Storage periods should be kept to a minimum where possible. Refrigeration units can be used for small quantities of material. Such facilities need not be expensive; for small propagation units, large capacity domestic fridges often suffice and larger enterprises may well find that simple low-cost refrigeration units are adequate.

Material should be transferred promptly from cold stores to propagation beds and should be labelled accurately and dated when inserted.

Preparation and handling of cuttings

Work areas

Work areas for propagation tasks, notably the preparation and insertion of cutting material, should be clean and tidy, organised and free of clutter so that work can proceed quickly and efficiently. All materials need to be close to hand, for example, cutting material for preparation, tools, trays and rooting hormone and an exit route for inserted material to be removed promptly to the propagation structure.

Good light is essential and worktops should have a smooth, wipe clean surface that can be disinfected regularly.

The work area should also have a logical flow to it for efficient working to maximise throughputs. Staff should have sufficient space to work and not be cramped. Seating should be adjustable and ideally wheeled to enable staff to move freely and work quickly. Benches should be of a convenient height for staff to work at comfortably without stretching or struggling, which induce fatigue and reduce productivity.

Work should flow smoothly with all materials close to hand

Team working

It is important to work well as a team, particularly when handling large volumes of propagation material during peak periods. Separate out the key tasks such as collection, preparation, insertion and transfer to the propagation structures but ensure these are well integrated to enable work to proceed smoothly with minimum disruption.

Usually, the most efficient approach is for someone to 'service' those team members tasked with preparing and sticking the material (collection is usually dealt with separately). This person should ensure everything runs smoothly and the team doesn't run short of tools, cutting material, trays, rooting hormone, etc. It is also their responsibility to ensure that cutting material is correctly labelled and taken away promptly, to ensure that conveyors don't become backed up. The team leader or servicer (they are often, but not always, the same person) should also check outputs to ensure work is progressing as required and is quality controlled.

Managing staff and the workplace environment

It is important to rotate staff periodically to avoid fatigue and so maintain productivity, especially during busy periods; as a guide, try to do this at least once a day so that team members don't spend all day, every day, repeating the same task. Many nurseries use seasonal, part-time staff and employ shift working for highly repetitive work such as this. This usually works well, provided staff are supervised and correctly trained.

Staff are always more productive when their working environment is safe and comfortable, so ensure there is adequate shade and ventilation during bright, hot periods and background heat is provided when required.

Give careful thought to the location and layout of the work area; often this is centrally located on site but needs to be near the propagation structure; they are not always the same thing, leading to excessive handling time and costs. On large or multi-site operations, consider mobilising the work so it can be located close to the propagation structure to minimise transport time.

Consider using mobile work areas such as portakabins or caravans, which can be adapted and moved as work proceeds and locations change.

Selecting cutting material

When selecting cutting material, it is important to avoid using very soft tip growth with high levels of nitrogen as the material is unlikely to root well or grow on to form strong, satisfactory plants. They are also difficult to manage and keep fresh. Similarly, older woody portions of stem should be discarded as such material is slow to root. Weak, thin shoot material should also be avoided as well as very thick portions of stem.

The best material to use is that grown in full light, which has a degree of flexing but is mature enough to snap crisply when bent sharply. Often, strong side shoots and lateral branches provide the best material and pruning out the leading shoots of shrubs, for example, helps to promote their development and the total number produced.

For hardwood cuttings, well-ripened wood of moderate size and vigour should be used to ensure the cuttings have adequate food reserves in the form of carbohydrates, to sustain root development and initial shoot growth. Shoot tips are usually discarded; central and basal stem sections make the best cuttings.

A well-organised team working in clean, well-lit conditions maximises output

Handling cuttings

Most cuttings are now rooted directly into pots or plug trays to ease and speed up handling and reduce root disturbance, leading to quicker establishment once transplanted or potted on. The preparation and insertion of cuttings can be time-consuming and laborious work. It can also be expensive and work should proceed quickly but be unhurried, with due regard to maintaining cutting quality.

When inserting cuttings, trays should be tilted gently forward to ease and speed up handling

ADAS studies during the 1980s identified several labour 'bottlenecks' in the preparation of cuttings, which led to the development of improved or preferred methods of handling, capable of up to 50% savings in production time. While secateurs were still used, the traditional knife was replaced by a scalpel-like disposable tool that was cheaper, safer and easier to use.

The work study principles and benefits remain true today and can be adapted to current practice. Tweezers, for example, can be (and are) used for the handling and inserting of very small, soft cuttings into plug trays and lightweight scissors or snips are popular with staff preparing cutting material for insertion.

Advantages of the ADAS system include:

- Easy to teach and learn
- Much quicker than traditional techniques where cuttings may be picked up and put down several times, therefore increasing productivity
- Reduced handling means less bruising and damage to cutting material and, as a consequence, less disease problems
- Quicker throughput limits moisture stress of cuttings, especially soft, leafy material in the summer
- Opportunities for staff to earn more and managers to stimulate productivity by bonus or piece-work
- Easier monitoring of work quality and outputs by team leaders or managers

The techniques were developed by former ADAS Advisor Brian Morgan. They can be adapted for batch preparation and insertion of easy to handle cuttings (e.g. semi-ripe conifer cuttings and shrubs propagated by tip cuttings such as *Buddleia, Cotoneaster* and *Hypericum*) or single/double preparation of more difficult material such as large leaved cuttings (e.g. *Rhododendron*), internodal cuttings (e.g. *Clematis*) or very small cuttings (e.g. heathers).

Figure 5 summarises the ADAS methodology for batch preparation and insertion, and Figure 6 the methodology for the preparation and insertion of one or two cuttings at a time.

Common to each method is the inclusion of wounding and hormone treatment of cuttings. Staff members are seated and work from a bench with trays gently tipped towards them for quicker and easier insertion of cuttings.

Lightweight scissors or 'snips' are ideal when preparing soft cutting material

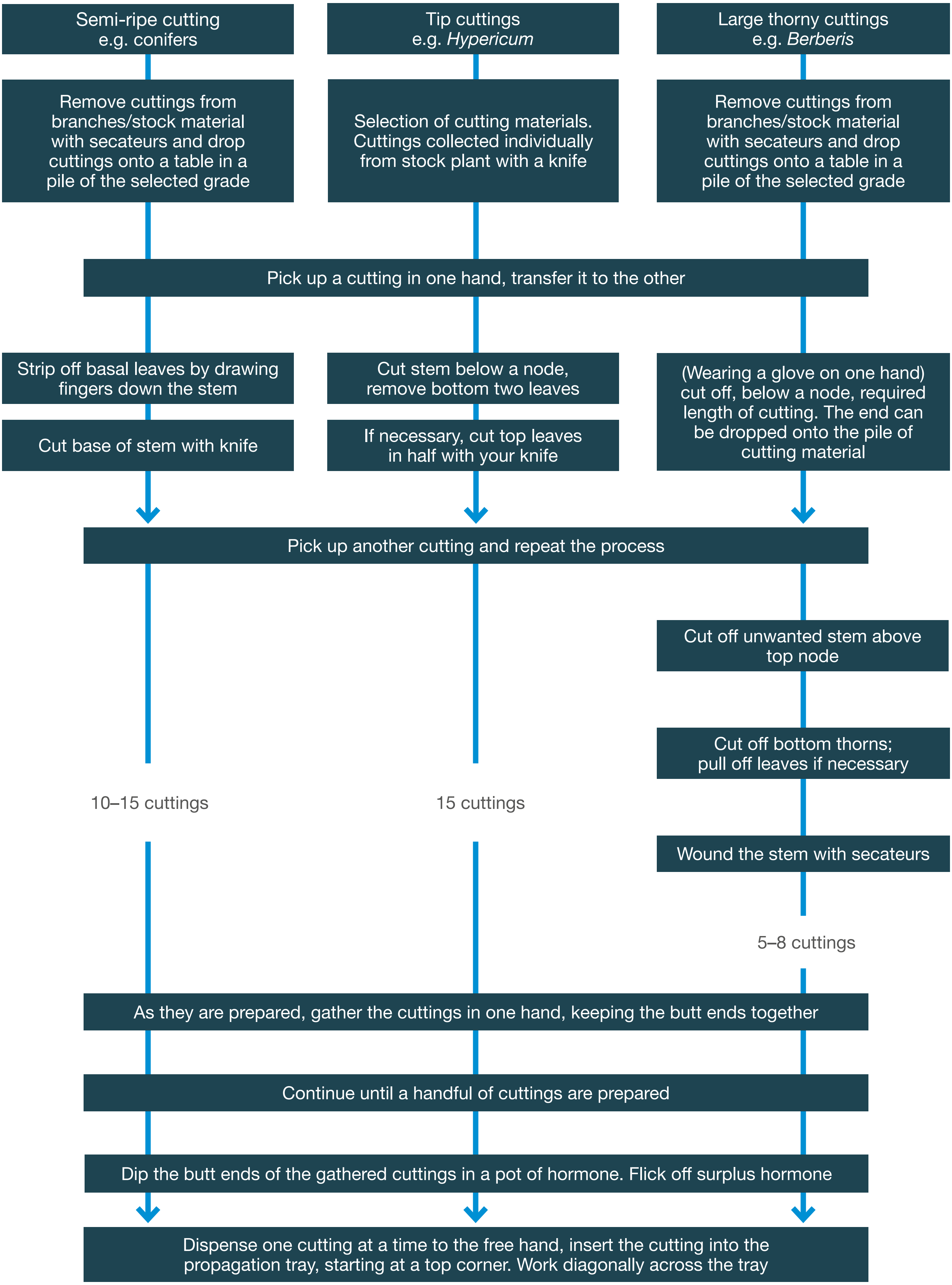


Figure 5. Batch preparation and planting of cuttings

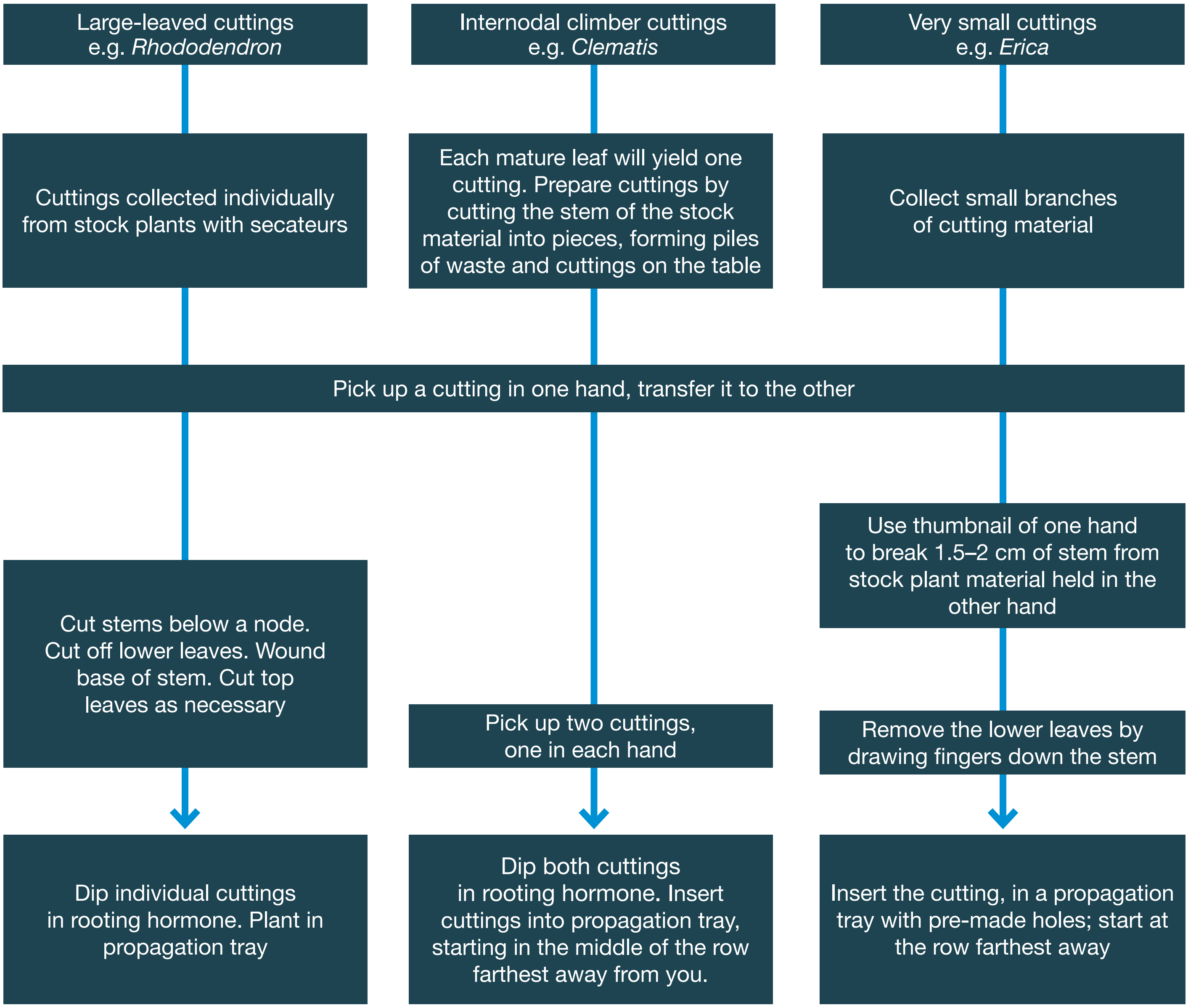


Figure 6. Preparation and planting of one or two cuttings at a time

Outputs and monitoring of work

Table 6 provides reference points for trainers and supervisors, and incorporates the average of the best 25% of staff in good conditions, the typical worker under typical conditions and the average of the worst 25% of workers in poor conditions.

Table 6. Times for preparation and insertion of cuttings

Type of plant material	Time (minutes per 1,000 cuttings)		
	Good	Typical	Poor
Hypericum species	50	60	100
Cupressus species	70	90	140
Berberis species (gloved hand)	150	280	380
Rhododendron species	180	270	420

These figures can be used as benchmarks when setting targets for staff and monitoring their outputs. However, take account of work conditions and the type of cutting material involved. The better and more organised the workplace, the greater the output.

Record rates on a daily basis and separate out preparation and insertion from the collection of cutting material; the two tasks are invariably done at different times by different staff. Keep records and the interpretation of data as simple as possible.

Use colour labels in trays to code and monitor individuals so that productivity and quality of work can be monitored.

Lean management

Lean management is a set of techniques that can be used to help reduce costs and add value to businesses. It does this by improving productivity and customer service levels, reducing plant losses, removing wastage and cutting lead times. It has been successfully applied in the UK to many horticultural businesses, including production nurseries, garden centres and landscapers.

Nursery studies have mainly considered order despatch activities and how productivity can be improved while coping with the usually large fluctuations in seasonal demand. The collection, preparation and insertion of cuttings, direct seeding into modules and subsequent transplanting also involve significant amounts of materials handling and staff time. As such, they are costly and lend themselves well to the process mapping and improvement principles of lean management. Several HNS businesses have successfully applied the principles of lean management to critically review and significantly improve their propagation practices. There is clearly scope to apply the principles and practices of lean management more widely, focusing on the specific tasks mentioned previously. It could also be usefully applied to other tasks, notably liner potting, budding and grafting.

The HTA (**the-hta.org.uk**) currently runs a bespoke service on lean management for their members, in partnership with Neil Fedden (**fedden-usp.co.uk**), one of the UK's leading authorities on the application of lean tools and techniques.

Wounding, leaf stripping and trimming of cuttings

Wounding

Wounding the basal stem area of cuttings such that the hardened outer layer of epidermal wood is partly removed to expose the cambium is known to stimulate rooting in many HNS subjects. Often, only a light scraping or wounding is necessary as in the propagation of soft evergreen species such as *Azalea*. With well-ripened or hardwood cutting material a heavier wound is required, usually as a precursor to the application of a rooting hormone product.

A simple scraping action is sometimes used with cuttings when it is difficult to either remove a slice of stem tissue or to penetrate into the stem with a knife blade, for example, with very small cuttings such as heathers. In fact, with narrow leaved evergreen species such as heathers and many conifers, the wounding effect of stripping the lower leaves or lateral shoots to enable their insertion into the rooting medium often creates an adequate wounding effect. Wounding may, however, increase basal rotting and so requires care and attention.

Wounding increases the quantity and quality of roots as new sites for root initiation are triggered when basal stem tissue is exposed. It enhances the uptake and effect of applied rooting hormones and it also increases water uptake from the rooting medium, important to maintain the turgidity of large leaved cuttings such as *Rhododendron, Magnolia* and evergreen *Prunus* varieties.

Wounding also encourages roots to develop further up the stem, offering a useful safeguard if basal roots deteriorate and rot off.

Physiology of wounding

The root initiating effect of wounding is due primarily to it stimulating a proliferation of new root initials and in turn more new roots from the vascular stem tissue. It also triggers the development of new parenchyma cells ('callus'), a known precursor to root initiation. The physical removal of a portion of harder basal stem tissue is also thought to enable greater water absorption, easier penetration of applied rooting hormones and, in some subjects, the removal of physical barriers to root emergence, such as thick walled stem cells. In at least some subjects, it is also likely that wounding facilitates the release of root promoting stimuli.

Usually, the more common slice wound is around 2 cm long and involves removing shallow slivers of tissue from the base of the stem. Normally, this is done with a sharp knife although the more practiced propagators are able to use the blade of a secateur for this, for example, with large evergreen cuttings such as *Prunus laurocerasus*. Often, a single slice wound made to one side of the basal area will suffice but, for hardwood or more difficult to root subjects, both sides may be wounded.

The depth of the wound depends largely on the species, the extent of lignification or 'ripeness' of the wood, the thickness of the bark and the overall stem diameter. In some cases, a heavier slice wound is required in order to penetrate the bark and expose cambial tissue. However, this must be done with great care otherwise the cutting will be damaged.

Shallow wounding should also expose cambial tissue but is generally more effective than heavy wounding, where it can be used; it is possible that shallow wounding proportionately exposes more cortex and phloem than xylem (wood) tissue as compared to heavy wounding, and it is this tissue rather than xylem from which new roots arise in cuttings of woody HNS subjects.

To be effective and minimise damage to the stem of the cutting, wounding must be done quickly and precisely using a sharp knife or blade. It also requires patience and practice to do it correctly.

Types of wounding

Slice wounding

Single slice wounding is the most common technique and useful for semi-ripe cuttings of subjects such as *Elaeagnus, Garrya, Ilex, Osmanthus, Prunus* (evergreen species) *Pyracantha* and *Viburnum* (evergreen species), for example.

The double slice wound can be used for subjects that do not root readily around the stem, such as some of the *Rhododendron* species, which often root on one side and so are more liable to damage when transplanted.

A single slice wound is suitable for a wide range of subjects and the most common type of wound used with HNS

There is also a third type of slice wound known as the modified slice wound, in which the cut is made further up the stem, leaving the bottom 1 cm unwounded. Although more common in America, this technique has proved successful for evergreen hardwood cuttings in which stem rot or poor rooting occurs at the base of the cutting, especially when there is the likelihood of the rooting medium becoming too wet.

Incision wound

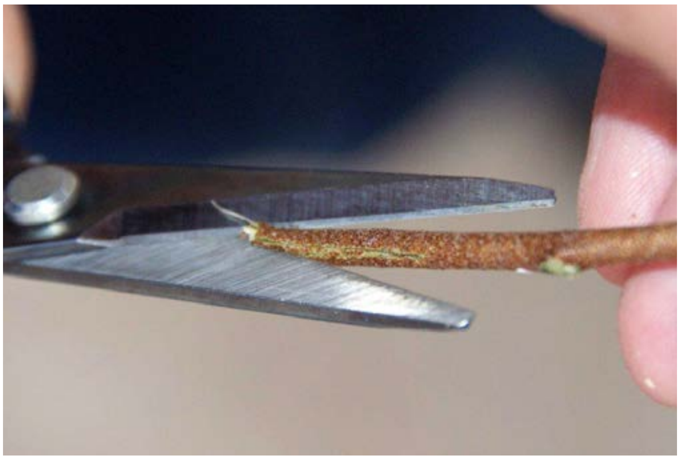
With this type of wound, no tissue is removed but the tip of a sharp knife is drawn down the basal 2–3 cm of stem so that it penetrates to the xylem wood. In some cases, up to three such wounds are made on the cutting. This technique is less common and not easy to do unless the cutting is supported, for example, held down on a flat surface with one hand while making the wound. Incision wounding is useful with thinner stem cuttings, for example, of conifers such as *Cupressus* and *Juniperus*, where slice wounding is more difficult to do.

Incision wounding is less common but useful for thin stemmed cuttings

Anatomical studies have shown that the callus that develops from incision wounding is derived mostly from the cortex (central pith) and that new cambium develops within this callus tissue, adjacent to the original cambium, so in effect forming a cambial 'bridge'. This callus is laid down as an outward pointing protuberance and it is at this point that a new root initiates and develops. This 'bridge' also develops following slice wounding.

Split wound

This wound involves splitting the basal stem area rather than surface wounding it. It is sometimes done when preparing hardwood cuttings, for example, of fruit tree rootstocks but requires care to avoid damaging the cutting. It also works well for summer cuttings of *Edgeworthia chrysantha*. Typically, such splits are around 1 cm deep.



Split wounding can be more effective at promoting rooting in some HNS subjects

Work at NIAB EMR with dormant winter cuttings of apple rootstocks (M26) in heated bins showed that incision wounding was more effective in promoting rooting than slice wounding and that split wounding was better still.

Good results were also evident with winter cuttings of *Acer platanoides* 'Crimson King' and *Castanea sativa*. Split wounding enables more callus to develop than incision wounding and a line of two outward pointing protuberances later differentiate to provide a source of potential roots rather than the usual single line with incision wounding. This may explain why split wounding can be more effective at promoting rooting in some HNS subjects than incision or slice wounding. The greater uptake of rooting hormone from split wounding over incision wounding may be another factor.

Leaf removal

Traditionally, basal leaves are removed from cuttings to prevent their deterioration on the rooting medium, which can trigger plant pathogenic infections such as *Botrytis*. The removal of the lower leaves is also frequently necessary to enable secure insertion of the cutting, for example, with heavy, large-leaved evergreen subjects with strong leaves and leaf petioles such as *Camellia, Elaeagnus, Ilex, Mahonia, Osmanthus* and *Skimmia*. This is especially so if the chosen medium is very lightweight, for example, a 50:50 peat-perlite mix. Usually, basal leaf removal also enables more cuttings to be inserted per tray.

Time spent removing leaves can, however, be significant, particularly when handling large numbers of cuttings. Work undertaken at Merrist Wood College to investigate leaf removal with a range of species to assess its necessity, found that only one subject (*Ceanothus*) from 17 subjects tested during the September to May period were seriously affected by *Botrytis* when basal leaves were left intact.

Another reason often given for the removal of basal leaves is that new roots arise more readily from the wounds created when they are pulled away, although the same study also found that many HNS subjects rooted readily from the base of the cutting. The study also highlighted that some subjects such as heathers and *Viburnum tinus,* which normally root from nodes rather than stem bases, rooted better when the lower leaves were left intact, possibly because of the better aeration around the basal stem area within the rooting medium. In the same trial, *Hebe rakaiensis* rooted more readily from leafless nodes (rather than when the leaves were left intact) than from the basal area of the cutting. It appears, therefore, that *Hebe* benefits from leaf removal. Table 7 summarises the results of this work.

Table 7. Effects of leaf removal on HNS cuttings

HNS subjects not requiring leaf removal		HNS subjects requiring leaf removal
Berberis (evergreen)	*Hebe* 'Eversley Seedling'	*Ceanothus* (in autumn)
Berberis thunbergii 'Rose Glow'	*Osmanthus heterophyllus*	*Hebe rakaiensis*
Ceanothus (in spring)	*Pernettya mucronata*	*Skimmia japonica*
Conifers (various)	*Pyracantha* species	
Elaeagnus pungens 'Maculata'	*Spiraea x bumalda*	
Heathers	*Viburnum tinus*	

Leaf trimming

Reducing the size of the leaf blade is often done when propagating large-leaved evergreen subjects such as evergreen *Prunus, Rhododendron* and sometimes *Camellia*, to reduce initial water loss from cuttings and to enable easier insertion into the rooting medium. Usually, it also enables more cuttings to be accommodated in a tray or pot. However, the cut surface is susceptible to disease infection and care should be taken to ensure the cuts made are clean. A protectant fungicide treatment post-insertion is also advisable.

Research with fog propagation indicated that untrimmed cuttings may perform better than those that have their leaves cut, as they can photosynthesise better and are less likely to deteriorate under such high humidity environments. However, fog is a more supportive environment than traditional mist or polythene systems.

Where leaf trimming is undertaken, the aim should be to reduce the leaf blade by around one-third to one-half in size.

Rooting hormones

To encourage quicker root initiation and more substantial root development, auxin-based root promoting hormone products are often applied to cuttings. These plant growth regulators are registered as pesticides and require training in their storage, handling and use. They are particularly useful for semi-ripe and hardwood cutting material and subjects known to be difficult to root. However, they are not usually essential for softwood cutting material or easy rooting alpine or herbaceous subjects, although their use may increase the uniformity and speed of rooting.

Literature mentions products based on the synthetic rooting hormone IBA (indole-3-butyric acid) which is non-toxic and effective over a wide range of HNS subjects and some use of NAA (1-naphthaleneacetic acid) and the naturally occurring root hormone IAA (indole-3-acetic acid) but, currently, there are no UK approved products containing IAA.

Following the commercial withdrawal of Seradix products (a range of different strength powder IBA formulations) and Synergol (a ready to dilute hormone solution based on IBA and NAA) during 2011, Rhizopon products (based on IBA or NAA and available as ready-use powders or water soluble tablets dissolved for use as dips or sprays) are now the standard products approved for use.

Powder preparations

These are convenient and simple to use, requiring fresh cuts to be made to the base of the cuttings shortly before dipping the basal centimetre of stem into the powder, shaking off the excess and inserting the cutting into the rooting medium. It is important not to overdose the cuttings, otherwise phytotoxic damage may occur at the cutting base. Where large numbers of cuttings are involved, they can be bundled into a convenient number and dipped but it is important to ensure all the bases are lined up evenly, otherwise some cuttings will receive more powder than others.

Cuttings with little or no natural moisture should be moistened with a damp sponge or the ends dipped in water to aid retention of the powder. Cuttings should be inserted immediately following treatment.

Cuttings should not be directly dipped into the bulk container of the product as this may lead to an early deterioration of the powder due to it becoming soiled or contaminated by moisture, fungi or bacteria. Instead, a sufficient amount for the work in hand should be transferred to a temporary container such as a plant pot saucer and any left over discarded. To maximise product longevity, containers should always be resealed and stored in a cool, dry place following the code of practice on pesticide use.

When inserting treated cuttings into the rooting medium, it is good practice to use a dibber, as pushing the cuttings into the substrate may displace much of the rooting powder.

Concentrated solutions ('quick dips')

Concentrated hormone solutions applied via a 'quick dip' treatment are also used in the rooting of HNS cuttings. With this method, the lower 0.5–5 cm of stem (depending on the size and type of cutting) is dipped for five seconds in a concentrated solution of hormone.

'Quick dips' are generally thought to offer quicker and more even rooting due to their rapid and easy absorption into cambial tissue from where root primordia emerge and through the base and sides of the cutting. Take particular care to ensure cuttings are not dipped beyond the recommended period and appropriate depth. Only use the amount required and avoid returning any surplus into any stock solution, otherwise contamination may occur.

Dilute solution soaking method (absorption method)

This technique involves soaking the base of the cuttings in a dilute solution of rooting hormone preparation for several hours prior to insertion into the rooting medium. The concentration to use will vary, depending on the rooting potential of the species involved.

Currently, this procedure is not widely used in the UK, largely because it is slow and requires considerable time.

All rooting hormone preparations should be used fresh whenever possible and stored in cool, dry conditions away from direct sunlight and in clean, sealed containers.

Rhizopon product range

The Rhizopon range of products, originally developed in the Netherlands but used worldwide, comprises ready-to-use powder preparations and water soluble tablets. The latter are dissolved in water to form solutions of varying concentrations for use either as absorption, total immersion (cutting dip), 'quick dip' or foliar spray treatments. However, this latter method is not currently approved in the UK after the cuttings have been inserted.

Rooting hormones are classified as pesticides and not all of the products in the Rhizopon range have approval for use in the UK, a number have also been revoked including products based naphthaleneacetic acid (NAA). Those that are approved (at the time of writing) are listed below:

- Chryzopon Rose (0.1% IBA), which is the equivalent of Seradix 1 and so suitable for softer cutting material
- Chryzotop Green (0.25% IBA), which is similar in strength to Seradix 2 (0.30% IBA) and so suitable for general propagation of semi-ripe cuttings
- Chryzoplus Grey (0.8% IBA), which is the equivalent of Seradix 3 and so more suitable for the propagation of hardwood cuttings
- Rhizopon AA Powder 1% (1.0% IBA)
- Rhizopon AA Powder 2% (2.0% IBA)
- Rhizopon AA Tablets (50 mg IBA per tablet), which are used to make liquid solutions of IBA at various strengths

Further information on Rhizopon products, including a useful 'rooting guide' to assist product selection can be found at **rhizopon.com/en**

Research with 'quick dip' solutions and powder preparations

HRI Efford studies considered the use of liquid 'quick dips' and powdered hormone preparations across a range of HNS subjects, including *Rhododendron,* some of which are especially difficult to root. Responses to a range of hormone treatments varied with cultivar.

Complementary work also compared liquid 'quick dips' and powder preparations with winter struck cuttings for a range of the more difficult to root HNS species, including *Camellia* 'Francie L', *Chamaecyparis lawsoniana* 'Lutea', X *Cupressocyparis leylandii, Elaeagnus pungens* 'Maculata' and *Mahonia bealei*.

This initial work suggested that 1,250 ppm of IBA can give equal or better results with some species than the previous standard of 2,500 ppm, although further work would be required to confirm this over another, perhaps poorer, rooting season. As in earlier work though, the 'quick dips' gave more consistent results overall than the powder formulation.

In continued work with *Camellia* 'Francie L' and 'E.G. Waterhouse', *Chamaecyparis lawsoniana* 'Columnaris Glauca', *Chamaecyparis lawsoniana* 'Lutea', *X Cupressocyparis leylandii, Elaeagnus pungens* 'Maculata', *Juniperus x media* 'Pfitzeriana Aurea', *Mahonia japonica* and *Thuja occidentalis*, IBA 'quick dips' gave similar or slightly improved rooting to powders (0.8% IBA) in terms of percentage rooting, with lower rates (1,250 ppm) producing similar results to higher concentrations with most species.

The speed of rooting among the evergreen shrub species was quite similar, whether treated with powder or liquid hormone but faster with the conifers where 'quick dips' were used.

In further comparative trials at HRI Efford over a four-year period using powders (0.8% IBA) and 'quick dips' of varying concentrations, with a range of autumn struck semi-ripe cutting material, the 'quick dips' gave better results than powder preparations. For example, there was a marked increase in the speed of rooting of *Elaeagnus pungens* 'Maculata' and *Mahonia japonica* from 'quick dips' (1,500 ppm IBA gave good results), while *Camellia* also rooted better from IBA 'quick dips' (2,000–4,000 ppm IBA).

Several *Rhododendron* cultivars were also considered, including the popular 'Cunninghams White' and 'Lady Clementine Mitford'. Although results were again variable, on average, 'quick dips' gave slightly better rooting than powder treatments albeit at stronger concentrations (3,750–6,250 ppm IBA). *Erica carnea*

‘Springwood White’ also rooted quicker when treated with ‘quick dips’ as compared to powder (0.8% IBA).

The trial also included *Chamaecyparis lawsoniana* ‘Columnaris Glauca’, ‘Pembury Blue’ and ‘Stardust’, along with *X Cupressocyparis leylandii*. Rooting was variable among the Chamaecyparis lawsoniana cultivars with, on average, few differences evident between powders or ‘quick dips’. However, *X Cupressocyparis leylandii* proved the exception, with the 1,500 ppm IBA ‘quick dip’ giving the best results.

Note: At the time of writing, there are no approved liquid rooting hormone products currently available for sale on the UK market containing high concentrations of IBA for the rooting of cuttings. The only such product containing IBA for making liquids is the Rhizopon AA 50 mg water soluble tablet and the maximum concentration of IBA currently permissible with these tablets in water is 1,500 ppm (30 tablets Rhizopon AA per litre of water).

Hormone dips and drying off times

A complementary study undertaken at HRI Efford during 1982 examined the effects of time of immersion in hormone liquid dips on the rooting of a range of HNS species to establish if cuttings required the hormone treatment to be dried off before insertion into the rooting medium. The treatments comprised a ‘rapid dip’ (immediate withdrawal) and a standard five-second ‘quick dip’ and compared the rooting of treated cuttings either inserted wet immediately after dipping in hormone or dried off before insertion.

The species used were *Escallonia* ‘Crimson Spire’, *Hebe* (species unspecified), *Hypericum calycinum* and *Juniperus sabina tamariscifolia*. All cuttings were struck during early February and rooted under polythene covers.

With each of the four species, there appeared to be no need to allow cuttings to dry before insertion into the rooting medium. In fact, with *Escallonia* and *Hypericum,* results were slightly better if material was inserted wet, immediately after dipping. With these two subjects, the ‘rapid dip’ produced equal or better results than the five-second ‘quick dip’.

The commercial significance of this work lies in the considerable time savings that accrue when cuttings are ‘rapid-dipped’ and inserted immediately rather than dried off following the standard five-second dip; this is an especially important consideration where large volumes of cuttings are being handled, and links well with the ADAS system for handling cuttings. However, the species used in this trial were relatively easy rooting and the findings need confirming through commercial experience with a wider ranger of HNS subjects that are known to be more challenging to root.

Propagation containers

Selecting containers that enable good root development is crucial for the successful establishment of plants following propagation and transplanting. Points to consider when choosing pots and trays include:

- The percentage take and uniformity you are likely to achieve. Pre-formed cells (cells that hold or bind the rooting medium together) enable easy grading of slower or more difficult to root subjects. Rooted material can also be readily spaced in situ
- The type and size of cutting. Larger cuttings will require a larger, deeper cell or pot, with more space
- The length of time the rooted cutting is likely to spend in the tray or pot. Choice is often a compromise between cost and the best size for the plant
- Future pot moves. Rooted cuttings are normally transplanted or potted on into larger containers, the size of which will also influence the type and size of that used for propagation. Avoid potting small rooted cells into large pots, particularly with slow growing or salt sensitive subjects, either use a larger cell for propagation or a smaller (intermediate) pot when transplanting
- Automation (for seeding or transplanting). Automation will save a lot of time but only if there is sufficient volume to justify the cost and the chosen pot or tray needs to integrate with this
- Root quality. Air pruning discourages damaging root circling while promoting strong lateral root growth and successful establishment. Trays that promote this may be particularly useful for vigorous, fast rooting subjects prone to root circling and rooting through into standing beds. Air pruning trays require good airflow underneath to work well, for which open benching or raised beds are needed

An example of root circling and constriction

Container selection

Module or plug trays of varying types and sizes are now used for HNS propagation and link well with automated seeding units and transplanters to ease and speed up handling. Growth checks are also less likely compared with standard trays as root systems remain intact and so undisturbed when transplanted.

Preformed plug trays with ready-to-use rooting medium, while more costly, are convenient and save time. However, very soft cuttings can easily snap during insertion, particularly where the rooting medium has been over compressed. Lack of uniformity can also be a problem in terms of moisture content and degree of compression.

Root curling and constriction of young plants causes stunting and poor growth but can be overcome by the use of biodegradable containers or those formed with grooved internal surfaces that channel roots down rather than round, so discouraging root circling (although good lateral root growth may also be constrained).

Biodegradable pots also save time when potting on and reduce nursery waste but can be awkward and difficult to manage, particularly in terms of water management and nutrition. Various materials are available including peat, coir and paper waste.

While plastic pots and trays can be reused, they require cleaning and disinfecting to reduce weed and disease carry-over and storing, which is costly. Therefore, new pots and carrier trays are often used instead or biodegradable types are used for some of the production. There is still some use of polystyrene trays, which are lightweight and easy to handle but they are difficult to clean and reuse and, like plastic, require disposal, which is costly.

Loose-fill and preformed plug trays each have advantages and disadvantages in their use; Table 8 provides a quick summary of each type.

Plug trays with a range of cell sizes are available and choosing the most appropriate size is crucial to successful propagation and post-rooting performance. Larger, heavier cuttings usually require a larger cell size, both in terms of diameter and depth. If the cells are too small, rooted material can become constricted, quickly dry out and run short of feed. Large cuttings and seeds can also be difficult to insert or sow accurately. Conversely, too large a cell can waste valuable space and increase handling and transport costs.

High levels of soluble salts and moisture around emerging roots can also develop and pose problems with large cells, particularly with slow rooting subjects.

A further consideration is the next action following rooting; for liner potting, small cells that root faster and are quicker to pot on are usually preferred while larger cells are easier to ‘hold’ and lend themselves better to potting on into larger pots, typically 1-litre upwards.

Cultural considerations

Containers, growing media and beds used for propagation must be well drained to avoid over-wet conditions, which will impede rooting. Drained sand beds are ideal (the sand should be of a grade similar to that used for capillary sand beds, comprising a range of particle sizes (30–40% greater than 0.5 mm, 40–60% at 0.5–0.2 mm and 5–15% less than 0.2 mm).

Good contact between the base of the trays or pots and the beds is important. Ideally, sand beds should be uncovered to maximise capillary contact and water movement between beds and containers. However, rooting through and subsequent growth checks can be a problem unless rooted material is removed promptly, especially with vigorous subjects. Permeable ground cover fabrics can be used over the beds to help reduce this problem but may impair capillary contact.

Table 8. The advantages and disadvantages of loose-fill and preformed plug trays

Loose-fill plug trays	Preformed plug trays
Advantages	**Advantages**
Cheaper to buy Available in a range of types and sizes Greater choice with propagation medium, particularly when mixed in-house Control over compression to minimise damage to cuttings during insertion, especially with soft material Arguably, greater uniformity in terms of moisture content and firmness	Convenient, ready to use and saves time otherwise spent filling trays Easier and quicker to extract during transplanting Available in a range of types and sizes depending on requirements Available pre-drilled for rapid insertion of cuttings Easier grading of rooted cuttings Little or no root disturbance at transplanting
Disadvantages	**Disadvantages**
Propagation media has to be mixed or bought in and handled separately, trays need to be filled Rooted material is slower to extract and handle when transplanting More root disturbance likely	More expensive to buy than loose-fill trays More limited choice of propagation media Can lack uniformity (variable firmness and moisture content)

While rooted plant material can be held back until required by environmental control and manipulating nutritional regimes, material should not be left for long periods before transplanting, otherwise root constriction will occur. This delays establishment and can lead to losses. Heavily matted root is easily damaged.

Rooted material that is actively growing can also quickly run short of nutrition or dry out, each of which can severely check subsequent growth and establishment and so require regular monitoring; in such situations, automatic capillary irrigation is ideal.

Propagation media and nutrition

Research into propagation media

While easy rooting subjects usually propagate quite readily in a range of media, the rooting of more difficult species is influenced more significantly, in terms of percentage rooting, by the quality of rooting and the speed of rooting.

Much of the early work with HNS propagation media was undertaken at HRI Efford during the early-mid 1980s. Principally, it focused on the development of granulated pine bark as a rooting medium in combination with peat to improve the speed and quality of rooting in softwood and semi-ripe cuttings and the use of controlled release fertilisers for post-rooting nutrition to maintain quality.

Initial work focused on bark as it was widely available and commercial experience with it had been developed elsewhere in Europe and in the United States. Early work in the States, for example, found that fine roots penetrated into bark particles or granules as well as between them, so enabling the development of stronger, denser root systems.

Mixes of 50:50 peat and bark and 100% bark were compared with 75:25 peat and grit, with and without controlled release fertiliser. The nitrogen immobilisation properties of bark provided an important buffer against the 'flash' release of nutrients, which impedes rooting, particularly under cover and where base heat is used.

While 100% pine bark promoted rapid root development, it was more difficult to manage during the weaning phase due to drying out. The 50:50 peat and bark mix improved rooting and cutting quality across a range of HNS subjects compared with peat:grit, provided that a controlled release fertiliser was incorporated. Without this, results were in fact poorer. This mix was also easier to manage than 100% bark.

Significantly, this work underlined the value of the nutrient buffering effect of bark-based mixes, which proved safer than peat:grit mixes where controlled release fertiliser was used, protecting young roots from the effects of high salts and, together with the structural benefits of bark, improving the quality of rooted material and the speed of establishment. At HRI Efford, while this effect was particularly striking with *Camellia*, all winter rooted evergreen and conifer species screened showed greater uniformity of growth.

In the same programme of work, trials with spruce bark did not give as good a result as pine bark.

Most recently, materials such a coir and wood-fibre have been successfully used for rooting cuttings, particularly coir, which has performed well across a range of HNS subjects when combined with bark for commercial HNS propagation.

Regardless of the materials used, propagation media should be:

- Readily available and affordable
- Clean, lightweight and easy to handle
- Physically uniform and stable
- Robust and able to support cuttings, particularly 'heavy' semi-ripe evergreen species
- Consistent in terms of pH (5.5–5.6 is the optimum for general HNS) and nutrient composition to maintain quality post-rooting
- Flowable in terms of pot or tray filling
- Sterile in terms of pest, disease and weed contamination
- Non-phytotoxic and readily penetrable by young roots
- Well drained and moisture retentive with an adequate air-filled porosity (AFP)

The rooting medium must be well drained and provide adequate oxygen around the base of unrooted cuttings, which utilise carbohydrate to form new tissue and so respire rapidly. Poor growing medium structure and drainage is a common cause of cuttings failing to root, especially in poorly controlled mist or fog systems. Damping-off diseases may also occur and exacerbate the problem.

At the other extreme, too much aeration can lead to excess callus formation at the expense of root initiation (commonly seen in *Camellia*, Leyland Cypress and *Taxus* species, for example) and cuttings becoming unstable. There must be a balance between good drainage and moisture retention.

Physical raw materials for propagation media

Peat

Peat remains the most popular and widely used bulk ingredient in nursery stock production. However, environmental and legislative pressures to reduce its use and seek alternatives continue. For propagation purposes, good quality medium-grade sphagnum peat is the most suitable as it retains moisture and is stable, uniform and chemically inert (which enables the easy adjustment of pH and nutrient levels).

In terms of structure, peats used for HNS propagation should have an air-filled porosity (AFP) of Index 2 (10–15%) although finer peats are often used for seed propagation and cuttings rooted in small modules, usually in blends with perlite or vermicullite.

Bark and other wood-based materials

Granulated pine bark has an open structure that provides propagation mixes with good drainage and aeration, so complementing the moisture retaining properties of peat or coir fibre. It is also lightweight, sterile, chemically inert and provides a useful buffer against excess water or soluble salts. This enables the inclusion of controlled release fertiliser products within mixes used for rooting cuttings, a major advance in terms of post-rooting nutrition.

Bark is especially good at promoting rapid root growth and the development of a fibrous root system, which hastens the establishment of cuttings when transplanted. However, it immobilises nitrogen leading to depletion and loss of quality, necessitating the use of base fertiliser or supplementary nitrogen in potting mixes (unless liquid feeding is available). This is usually unnecessary in propagation mixes where the inclusion of controlled release fertiliser (or liquid feeding) provides sufficient post-rooting nutrition.

Granulated pine bark is preferred to spruce and larch bark as it usually has fewer volatile oils. It also has lower calcium levels and a lower pH value and so is more suitable for HNS subjects.

Bark is now widely used for the rooting of cuttings, usually in mixes with peat or coir to aid nutrient and water retention during post-rooting nutrition. The addition of peat or coir enables easier insertion and support of cuttings within trays or pots.

Bark can have a useful suppressant effect on soil and water-borne disease pathogens, notably *Pythium* and *Phytophthora* both of which are invariably linked with the ‘damping-off’ of seedlings and cuttings.

As it becomes more widely available, wood-fibre is now also being used in propagation media.

Coir fibre

The physical characteristics and water-holding capacity of coir fibre are quite similar to peat. It is, therefore, easy to over water and often appears dry on the surface while being adequately wet underneath. But it can also dry out quickly and so requires particularly careful management.

Nitrogen immobilisation can occur, leading to leaf yellowing symptoms. These symptoms may also be due to the initially high pH of coir, a point to consider when adding lime. While coir is now used more widely for container HNS production, usually in blends with peat and bark, it is also an excellent propagation substrate for the rooting of cuttings, particularly when combined with granulated pine bark (50:50 by volume).

Sand and grit

Sand and grit are relatively cheap and available but vary in their physical and mineral composition. They are also heavy and add considerable weight to a propagation medium, which is an important handling and transport consideration. They also retain little water and so require blending with other substrates, usually peat. As such, their commercial appeal has diminished in favour of more lightweight materials, notably bark and coir fibre but also perlite and vermiculite.

For some subjects, sharp sand, a non-calcareous sand derived from sandstone or granite, should be used, with a good spread of particle sizes (0.01 mm to 3 mm). Addition does provide the necessary sharpness and physical support during rooting; *Taxus,* for example, and many other conifers respond well to the use of a sharp sand as do *Magnolia* species (although, these also root well in 50:50 blends of peat with bark). Other HNS subjects, though, produce long, unbranched rather brittle root systems rather than the more fibrous types developed with bark.

Perlite

An inert material of volcanic origin that is heat treated to form stable aggregates, perlite is clean, easy to handle and lightweight to use. It is widely used for seed and softwood or semi-ripe cuttings due to its good drainage characteristics and is often used with peat or bark where free drainage is required, usually at rates of 20–30% by volume. Unlike vermiculite, it has little or no buffering capacity but it is sometimes partnered with it, usually with medium grade sphagnum peat.

For HNS cuttings propagation, the horticultural grades (medium or coarse) of perlite should be used and not those containing a high percentage of fine particles or dust.

Vermiculite

Vermiculite is a naturally occurring lightweight mineral also created by heat treatment to produce a material of high porosity and good air to water ratio, with a usual pH of 6.0–6.5. It is often used as a surface dressing in seed propagation over trays or modules to retain moisture, protect seeds and exclude light, and in propagation media as a mineral buffer against excess salts, usually at 20–30% by volume.

HNS cuttings generally root better in vermiculite if the larger particle sizes are used. *Magnolia* cuttings respond particularly well to vermiculite when it is mixed with peat, for moisture retention and support of the cuttings.

Rockwool

An inert, fibrous, lightweight and sterile substrate derived from volcanic rock, capable of rooting HNS cuttings, due largely to its high air capacity. Used quite extensively during the 1980s, commercial experience with it was mixed. While the slow-rooting *Berberis* types, *Ceanothus, Cotoneaster, Elaeagnus, Escallonia, Garrya, Lavatera, Spiraea, Viburnum davidii* and *Viburnum tinus* rooted well, others proved less responsive, notably *Cytisus, Euphorbia, Pernettya* and winter cuttings of *Ilex* and *Laurus nobilis* and *Photinia*, which did better in a peat and bark medium.

It is not widely used for HNS propagation, due largely to its high cost, variable results and concerns about the environmental impact of its use and disposal.

Nutrition

Historically, nutrients to maintain quality and promote root development in a propagation medium were provided by superphosphates, ground chalk, low rate base fertiliser dressings and, prior to the development of peat-based media, the inclusion of loam. However, modern production that builds on the HRI Efford work uses more efficient controlled release fertilisers that provide nutrition in line with temperature and growth requirements. Ground chalk or Magnesian limestone ('Dolodust') are now used for pH adjustment.

The principal benefit from fertiliser incorporation in the rooting medium is the improved establishment and early quality and speed of growth of cuttings once potted on. At HRI Efford, while this effect was particularly striking with *Camellia*, all species screened showed greater uniformity of growth and, while the effect was less obvious six months after potting, it was still evident among *Camellia* and *X Cupressocyparis leylandii*.

In early studies with winter rooted evergreens and conifers, including *Camellia, X Cupressocyparis leylandii, Griselinia* and *Pittosporum,* leaf-tissue analyses prior to potting on of rooted cuttings also showed that the inclusion of controlled release fertiliser reduced nitrogen depletion from the cuttings during propagation, which helped to improve foliage colour, particularly among conifers.

The type and rate of controlled release fertiliser used in propagation media is critical, especially under the higher temperatures of polythene covers (where there is less leaching of excess salts compared to mist). In early trials, rates of 0.5 and 0.75 kg/m^3 of medium-term products gave good results, particularly with 50:50 peat and bark mixes. Longer-term products (12–14 month) were safer and enabled higher rates of use (0.75 kg/m^3), with the inclusion of bark. This combination became the HRI Efford standard propagating medium for all winter propagation under polythene.

Effect of controlled release fertiliser in the rooting media, left liquid feeding following weaning and, right, fertiliser incorporation in the tray

Subsequent work found scope for increasing the fertiliser rate beyond 0.75 kg/m^3 of the 12–14 month product, provided bark was used, which led to the use of higher rates (typically, 1.5–2.0 kg/m^3) by growers, for example, with vigorous species rooted under the safer environment of mist (rather than polythene tents).

HRI Efford work also indicated that bark mixes produced more new root growth compared with cuttings rooted in fibrous peat and grit mixes, particularly where fertiliser had been included. As in previous trials, these benefits continued after potting, resulting in faster establishment, earlier growth and greater uniformity within the batch; effects that were still evident six months after potting.

The benefits of including controlled release fertiliser with bark in the rooting medium, from left to right, no feed during propagation, liquid feeding after weaning and fertiliser incorporation

The HRI Efford studies also found that the type and rate of fertiliser to use varied with the time of propagation and in turn the system used. During the spring and summer months, for example, when mist or fog environments are widely deployed, there is scope to use higher fertiliser rates (1 kg/m^3 of 8–9 or 12–14 month products gave excellent results across a range of subjects) but for autumn and winter propagation under polythene covers, where leaching is minimal, lower rates (0.75–1.0 kg/m^3) of a 12–14 month product were safer yet still provided sufficient nutrient reserves to maintain cutting quality until spring potting.

Seed

Seed sources

Although there are many good seed houses dealing in plants from temperate climates, which supply seeds in excellent condition, harvesting seed from local sources to augment commercial supplies and broaden the range of species has advantages. For example, it enables the identity and quality of the material to be specifically determined and control over the timing of collection. In turn, this creates the potential for greater certainty and so offers a more reliable outcome. The provenance of locally collected seed also provides a strong indication of the likely performance of that particular species in the local environment.

If obtaining seed from local sources, the most important consideration is to determine and confirm the identity of the subject to be propagated and its trueness to type. It is also important to assess the available plants that are producing seeds in order to select the most suitable parent. More often than not, there will only be one seed-bearing parent plant available but there may be several specimens that exhibit sufficiently similar characteristics to demonstrate reasonable uniformity. At this stage, it is also useful to determine whether these potential parents are seedlings or are of vegetative (clonal) origin, as this will govern the limits of the available gene pool and its potential for variation.

In situations where other relevant, related species are growing in the same area, the potential for cross-pollination and the production of hybrid offspring should be considered and thus seed collection avoided from such potential parents.

Seedling and plant vigour are largely governed by genetics, and seed collected from a group of plants of the same species that cross-pollinate is more likely to have good vigour. As such, it is likely to perform much better at the seedling stage compared to progeny resulting from seed collected from isolated, self-pollinated individuals. Monitoring each seed source is, therefore, important to ascertain its suitability for future seed collection.

Trueness to type of the resultant seedlings also requires checking because, while a parent plant itself may appear to be correct, it may in fact be derived from a cross and characteristics that indicate this only tend to appear in the next generation.

Influence of parent plants on seed production

When collecting seeds from plants that have only recently matured, be aware that most food reserves are still being channelled into vegetative growth. Normally, therefore, the level of seed production will be relatively sparse and the quality of any seeds produced, especially in terms of the amount of stored food reserve, may be low.

As the plant progresses further into the mature phase, the amount of annual vegetative growth declines and seed production in both quantity and quality potentially improves. At this stage, vegetative extension growth has moderated considerably and the plant has reached the greater part of its ultimate height and spread. This increase and stabilisation of the growth pattern is accompanied by maximum leaf area and by an increased propensity to produce flowers. As a result, high-quality seeds may follow, until the senile phase approaches, when there will probably be a flurry of heavy crops prior to death.

The established mature plant is, therefore, diverting its resources into the development of both the embryo and the food reserve of the seed, and a good crop can be anticipated. However, especially in the UK, this theoretical level of seed production can be affected by environmental conditions in any particular year, for example, frost occurrence at flowering and low summer temperatures, as well as the incidence of leaf pests and diseases.

Season of collection

Normally, it is anticipated that seeds will be collected just prior to dispersal when all of the biological processes involved with the development of the seed have been completed. At this stage, the seed is mature and will be suitable for germination or storage.

However, there are a significant number of species of woody plants (such as *Acer campestre, Acer palmatum*, *Carpinus betulus*, *Daphne mezereum*, etc.) for which this is not necessarily the best strategy as, by this stage, the seed will have developed intransigent dormancy conditions. It is, therefore, prudent to collect such seeds at an earlier stage.

Periodicity of seed production

There are many tree species (including *Fagus sylvatica, Quercus robur* and *Sorbus aria*) that exhibit a periodicity in the production of seed crops and, as such, the production of prolific harvests will only occur at infrequent intervals, referred to as mast years. In such cases, it is important to gather sufficient crop in the productive years to account for the deficiency in the other years by storage.

This more or less genetically controlled condition should not be confused with a failure to crop due to a particular prevailing environmental condition, such as frost incidence, which may affect the initiation or development of the seed at flowering or fertilisation.

Seed viability, vigour and longevity

When determining the sowing rates for a sample of seed, in order to achieve a predetermined density of seedling production, it is essential to know what proportion of the sample is viable and so, potentially, capable of developing into a seedling.

Viability

A viable seed is one that has the potential to germinate and establish as a seedling, given the provision of suitable conditions and, thus, be capable of producing both a sufficient root and shoot system to ensure continuing autonomy.

There can be several reasons for the lack of viability in seeds, notably:

- The absence of an embryo
- The presence of a malformed embryo
- The lack of a sufficient food reserve
- An inability to mobilise or use the food reserves
- Physical damage engendered by the collection, extraction and cleaning treatments
- An attack by biological organisms causing degradation
- Ageing to an irreversible state of deterioration, which effectively does not allow the process of germination to proceed

The potential viability of a seed lot is usually expressed as a percentage of the number of seeds present and reflects the proportion of the sample that is capable of satisfactory germination. This figure, however, only represents the potential at the time that it is measured; seed viability naturally diminishes over time and is influenced by many environmental factors, making accurate assessment of the rate of decline very difficult.

There are, however, several techniques for the assessment of viability under nursery conditions:

- Cutting test
- Germination test
- Excised embryo test
- Staining techniques

The cutting test is the simplest operation to carry out, as it relies on exposing the internal tissues of the seed to observation. From this, by a visual assessment, the status and condition of the embryo and food reserves can be determined.

The germination test provides a relatively more accurate assessment of the potential for germination that might be achieved under optimal conditions. Seeds can be subjected to reasonably constant and reproducible environmental conditions that are suitable for initiating and sustaining the process of germination. The results are measured by the seeds' responses and these can then be evaluated.

The excised embryo test is more complex and requires the availability of laboratory resources and the development of expertise in being able to dissect out the embryo without damage.

The technique involves the removal of the embryo from its surrounding tissues and seed coats and its transference to a moist situation in a petri-dish or similar receptacle where it can be suitably incubated and any responses assessed.

The use of staining techniques in determining the presence and pattern of living tissue within the seed can be achieved using a range of staining agents. There are a number of such chemicals that will achieve useful results permitting a visual interpretation of seed viability.

Vigour

The measure of viability provides the overall picture of the status of a seed lot but experience will indicate the potential this level will have on the rate and strength of seedling emergence during the germination process. This aspect is described as the vigour of the seed lot.

When a seed is fresh and ready for dispersal there is normally no deterioration in the seed structure or the corresponding physiological processes; the maximum number of embryos are viable and the necessary metabolic processes are at maximum efficiency. When the germination process is delayed, this causes damage and the deterioration of seed structures and processes will ensue.

Longevity

The term longevity, in the context of seed viability, is used to describe the length of life of a seed sample during which some useful capacity for germination is retained. It is, however, rarely defined in a measured way and is often used in a relative or comparative fashion to determine the effect of storage conditions on maintaining viability. In practice, this period can vary from a few days as in the case of *Acer rubrum*, *Acer saccharinum*, many willows and poplars to many years as with the hard seeded *Leguminosae*.

Collection and extraction of seeds

Seed collection and initial handling

Seed collection lends itself well to businesses with an extensive catalogue of subjects grown in relatively modest quantities requiring small samples of seed each year. However, it is time-consuming and quite specialist work and the economics of this approach must be carefully assessed first and compared with commercial sourcing.

When collecting seed, the main objective is to harvest high-quality seeds in such a way that there is no detriment to the integrity and condition of the seed and its contents so that the highest level of viability and condition is maintained. Do not waste resources collecting substandard seed.

The collection of seeds or fruits requires a number of preliminaries to be considered:

- Obtain the necessary permissions if required
- Determine the source and confirm identification
- Assess likely seed quality
- Assess seed quantity (monitor through season)
- Assemble the required collection equipment

The actual collection procedure will also require some attention:

- Collect when conditions are suitable, avoid very hot, cold or very rainy periods in which seeds can quickly deteriorate. Seed collecting in such conditions can also be arduous work
- Adopt suitable methods to avoid seed deterioration

- Only collect manageable amounts of seed and keep it out of direct sunlight. It would also be prudent to provide a cool box for temporary storage and transport in order to remove the 'field heat' from the seeds
- Collect a clean sample, remove leaves and other detritus as you go
- Check to ensure there are no obvious pests, diseases or surface moulds present
- Do not collect fruits until they have reached such a stage of maturity that they will release the seeds easily
- Spread out collected seed evenly and thinly on a clean surface to prevent heating up
- Provide good air movement and turn seed periodically until the batch is cleaned, extracted and dealt with
- Wear gloves, dust masks, etc., when necessary, to avoid allergic reactions
- As large amounts of big seeds or fruits are likely to heat up as a result of their normal metabolic activity, the material should be packeted into smaller units
- Keep accurate records of all seed collected for reference and future comparison

Seed collection and ripening methods vary with species and in turn the method of seed dispersal. For example, acorns (*Quercus* species) and chestnuts (*Aesculus* species) can be harvested from the ground while others, such as elm seed (*Ulmus* species) require sweeping up. Alternatively, sacking or polythene sheeting can be laid on the ground around the plant that is then shaken to remove the seed. With some species (for example, *Fagus sylvatica*), nature must take its course and the seed collected over a period of time; this requires diligent monitoring to judge when best to place netting or sacking down for collection.

Berries usually require hand picking from the plants, although major specialist seed producers collecting large batches of seed, generally mechanise the work.

When hand picking seed, very dense plant growth invariably makes the use of a collection sack difficult and, in such situations, it is often quicker to place sacking or sheeting underneath the tree and allow the seed being picked to fall naturally onto it.

If collecting seed by hand, care should always be taken to avoid removing spurs or small branches that will bear subsequent crops. A lack of diligence in this respect can quickly reduce future seed crops and increase the cost of seed cleaning work.

Use hessian sacks, rather than polythene bags for collection of seed. Label promptly, with the correct name, date of collection and source of material. Use waterproof labels and marker pens.

Seed extraction

The principal objective in the extraction of a sample of seed from its surrounding fruit is to avoid damage to the structure and integrity of the seed or to reduce the level of seed viability.

The extraction of seeds from the fruit is achieved by either of the following processes:

- Separation of the seeds from multi-seeded fruits into single entities
- Separation of the seed from the remainder of the fruit, in order to obtain a clean sample

The process should be achieved:

- With the minimum of damage to the physical integrity of the seed
- With the retention of acceptable levels of quality
- Without altering the internal physiology of the seed and especially without enhancing any dormancy conditions or inducing secondary dormancy
- Without enhancing any seed coat condition associated with moisture permeability
- Without critically affecting the moisture content of the seed

Methods of seed extraction

The actual methods of extraction are as disparate as the individual types of fruit themselves. It is possible to describe various generalised methods of seed extraction but, importantly, each sample should be dealt with on an individual basis. The process should be monitored continuously in order to modify the action of equipment or the treatment process itself to suit each sample. The status of the seed should be regularly assessed in order to maintain quality control and so produce a sample with the highest capacity to regenerate.

Extracting seeds from dry fruits and cones

This relates to those plants that liberate their seeds from the fruits simply as a result of drying and is quite a common process. As water is withdrawn by the parent plant or is lost by the action of external factors, the fruits mature to the point at which they open. Fruits can open gradually, disintegrate or even explode depending on their mode of dispersal.

Fruits of this type should be collected as they become fully mature and are approaching the stage at which they will open to disperse the seeds. The time of collection is often critical as drying of the fruits, using an artificial source, will not necessarily produce the correct drying process resulting in the points of weakness not being triggered so that fruits remain stubbornly closed, for example with *Ceanothus*, *Euonymus* and *Magnolia*.

The cones of conifers, in general (not those producing a fleshy fruit or serotinous cones), normally open and liberate their seeds as a result of a natural drying process. As harvested cones are necessarily collected before they open and liberate their seeds, the cones can be dried artificially in gentle, dry warmth where they will respond without difficulty and open successfully. On a large scale, this activity can be undertaken in a suitable kiln in which the cones can be tumble dried at no more than 60°C. This will achieve satisfactory results and a clean sample of seeds will be produced.

If the cones are of the type that break up to liberate the seeds, it will be necessary to fan the resulting mass to separate the seeds from the scales.

Serotinous (closed) cones can usually be opened by flaming them over a fire. However, if they are particularly tightly closed and do not respond, they should be soaked, then frozen, thawed and dried. The seeds will shake out once the scales open.

Extracting seed from fleshy fruits

Fleshy fruits of whatever type (drupes, pomes, berries, etc.) have generally evolved as a mode of dispersal for the seed and represent the various ways of attracting an animal by providing a food resource. The attraction is often enhanced by the development of colour that identifies the food resource and the stage of their development in terms of palatability.

Fruits of this type will, more often than not, contain seeds with a 'hard' seed coat, which provides the protection for it to avoid damage as it passes through the animal's digestive tract. Usually, the seed coat will have been degraded close to a level allowing water permeability when it is eventually expelled. Artificial extraction does not achieve this degradation so it is important that the process does not enhance the condition that usually occurs when the seed is dried more than is necessary to surface dry.

Soak the fruits in warm water for a period to encourage fermentation of the flesh; eventually, with some agitation, it will separate and float so that the seeds fall to the bottom. The liquid can then be decanted off and the seeds washed clean and then surface dried. Do not allow the process to go beyond the stage at which separation can be achieved to avoid any detriment to the seeds. Wash the seeds with a small amount of detergent in order to remove any residual fat that may affect water uptake by the seed or any flesh or skin that may contain germination inhibitors.

Seed dormancy

When a viable and quiescent seed is subjected to conditions suitable for germination and it does not respond, the seed is said to be dormant. This implies that there is present, in the make-up of the seed or its coverings, a mechanism for preventing germination.

Although dormancy presents difficulties for the propagator, the condition is an evolved strategy that particular species have developed to enhance survival, or it may also reflect the need to spread germination over time. It has evolved to ensure that germination and establishment occurs when the most suitable environmental conditions for the survival of the seedling are available and conversely that germination is prevented when conditions are adverse. It may also delay germination spasmodically over a number of years in order to achieve success when suitable years occur.

Some seed coat conditions have also evolved to protect the seed from digestion while passing through the gut of an animal.

Propagators need to recognise and overcome these limitations to enable seed germination to proceed in order to achieve the best productivity.

In broad terms, seed dormancy in woody plants from temperate climates can be attributed to:

- External conditions, in which the seed coat may prevent the uptake of water, restrict gaseous exchange or limit embryo expansion
- An immature or rudimentary embryo
- Biochemical conditions that inhibit endogenous physiological reactions that form part of the germination process

Hard seed coats

Many plants (for example, *Crataegus*, *Prunus* and leguminous species such as *Acacia*, *Cytisus* and *Ulex*) produce seeds that develop a hard seed coat, the commonest form of which is a hard stone-like or shell-like structure.

The effective method of reducing this to a water permeable condition varies from caustic digestion, through heat treatment, physical and biological degradation, to warm water soaking depending on the degree of seed coat development.

Tough seed coats

The types of seed coat that constitute this category are quite varied in their constitution but all are to some degree leathery. They are, when fully developed, pliable, tough and impermeable to water and have a more or less constant and uniform consistency or sometimes have a reticulate structure.

All are intractable, insofar as the artificial removal of seed coat material is difficult and often hazardous. Although it is possible to degrade them by digestion with acid or other caustic materials, this is usually difficult to do. Though slower, the use of a natural material that degrades the seed coat biologically is safer and can be done effectively, if not with great accuracy.

Waterproof seed coats

Although fairly uncommon, there are several plants (including *Aesculus*, *Cedrus* and *Wisteria*) for which the seed is maintained in a quiescent state by a surface waterproofing, which prevents the ingress of water. Materials such as waxes, fats and oils are the most commonly found agents. Often the condition is only short lived but, should it need to be removed, hot water soaking is usually sufficient.

Immature and rudimentary embryos

In many species of woody plants (for example, *Fraxinus excelsior*, *Ilex*, *Podocarpus* and *Taxus*), the process of germination is prevented simply because the embryo has not developed to a sufficiently mature stage for germination to occur when conditions are suitable. The condition can be mitigated by storing the imbibed seed at a warm temperature (around 20°C) for a sufficient period (usually 4–12 weeks depending on the species and season) to allow the maturation process to be completed.

Endogenous dormancy

This type of dormancy control occurs within the seed itself and depends on the presence of particular chemicals that prevent or interrupt the normal patterns of metabolic activity and germination.

Currently, it would appear that the prevention of germination of the imbibed seed is caused by the presence of inhibitors that the seed has metabolised during the maturation process. The chief recognised agent is abscisic acid. Further activity then depends on the reduction of the level of the inhibitor with a corresponding increase in the production of the growth promoter (usually cited as a gibberellic acid). This type of dormancy can be mitigated by the exposure of the imbibed seed to a period of cold temperature.

Epicotyl dormancy

The condition known as epicotyl (double) dormancy, although not uncommon in herbaceous plants, especially the *Liliaceae*, is not common among woody plants in general. It is typified by the emergence of the radical, from the imbibed seed, during the first warm period after dispersal; however, the plumule requires a period of chilling before it will germinate when conditions are again suitable. This usually means that the seed bed is occupied for two growing seasons before the seedling is produced. Examples among woody plants that have adopted this strategy include *Chionanthus*, *Davidia* and some North American species of *Viburnum*.

Multiple types of dormancy

It is not uncommon to find among woody plants from temperate climates, the development of more than one type of dormancy. In nature, this usually ensures the spread of germination over more than one year.

This more complex picture creates further difficulties for the propagator but it can be dealt with by eliminating the conditions in sequence in order to achieve germination. In some species this entails, at the extreme, all three modes of dormancy and involves in order of elimination a seed coat condition, an immature embryo and a chilling requirement. The classic exponent of this state is *Fraxinus excelsior*.

Avoiding dormancy

Dormancy caused by intransigent seed coat conditions are conventionally overcome by the degradation of the seed coat by caustic agents for swift results or natural methods that are relatively long term and difficult to develop accurately. Ideally, the most successful outcome would be to be able to collect the seed before any of these conditions have developed in the maturation process of the seed.

Although it is currently not feasible to avoid endogenous dormancy conditions, it is possible to avoid those dormancy conditions that are controlled by the condition of the seed coat, by harvesting the seed as soon as it is mature and before the seed coat condition has developed.

Even 30 years ago, it was barely recognised and accepted that the collection of the seed, at the point of maturation and before the development of the impermeable seed coat, was feasible and could be undertaken without any potential damage.

However, the concept is not new and as long ago as 1945, Van der Graaf in the Netherlands published on this topic in relation to *Daphne mezereum*. Plants in as widely divergent genera and species as *Acer campestre*, *Acer truncatum*, *Hamamelis mollis*, *Carpinus betulus* and *Viburnum lantana* have all been shown to respond to an adaptation of this technique.

Seed storage

Principles of seed storage

In essence, the principal aim of any storage technique is to extend the longevity of a seed lot by maintaining the highest feasible level of viability for as long as possible.

This extension is achieved by the provision of environmental conditions that have the effect of reducing the rate of deterioration of the seeds. The most usual are those that slow the metabolic processes, especially the rate of respiration of the seed and that can be applied under practical circumstances. In practice, three factors are relevant: temperature, seed moisture content and the gaseous constitution of the atmosphere.

The rate at which biological processes occur is related to temperature and, as such, this is one of the most commonly manipulated parameters in seed storage.

As a general rule, the colder the temperature, the slower the rate of reaction will be. Thus, at a low temperature, the rate of respiration is lower, food reserves are mobilised and consumed more slowly and the consequent ancillary processes are slower. Any reduction of temperature will enhance longevity but the most effective response is achieved at the lowest temperature that the seed will tolerate without damage.

In practice, for most woody plants of temperate provenance, a storage temperature of 2–3°C is adequate to achieve the level of longevity required for commercial purposes. At this level, a normal household refrigerator can be manipulated to maintain such a temperature.

Historically, the most favoured method of increasing the longevity of a seed lot is to reduce its moisture content but many species of woody plants store their food reserves in the form of proteins or fats (as well as carbohydrates) and these materials do not lend themselves easily to rehydration.

Although rarely practiced, it is also possible to slow metabolic processes in seeds by reducing the availability of oxygen. However, this possibility should be treated with care as a wholesale removal of oxygen could induce an anaerobic response if the other parameters are not also controlled.

Practical aspects of seed storage

For successful storage, seed must be mature, with a developed and quiescent embryo and have a stable food reserve. Generally, seeds with a high oil (fat) content, such as *Abies* and *Cedrus,* don't store well.

Good seed storage maintains viability and enhances longevity

Seeds should be processed and stored as quickly as possible following collection, while fresh and in good condition; they are then more likely to maintain viability in store and deteriorate much less. While some nurseries still use cold storage or other chilling techniques to break seed dormancy, many now buy in their seed requirements, pretreated from specialist seed suppliers and cool store them on arrival until conditions are right for sowing.

Usually, a temperature of 2–3°C will suffice for general seed storage, although some nurseries report good results at 1–2°C, which reduces the likelihood of seeds starting to germinate during storage. For many species, ambient storage using airtight containers kept in a cool place may also be used, as such seed can retain its viability for at least a year except under very adverse conditions. Controlled temperature storage is advisable for seeds to be held for longer than one year.

The relationship in store between moisture and temperature is critical. Many kinds of short-lived seeds lose their viability completely if their moisture content diminishes significantly while other problems arise (notably, disease infection and spread) with increasing moisture levels, so it is essential to strike the right balance.

Generally, reduced temperatures prolong the storage life of seeds and help to offset the adverse effects of high moisture content. Usually, seed is stored in sealed polythene bags or small sacks to reduce moisture loss.

Some subjects require fresh seed for successful germination, for example, those belonging to the Umbelliferae family such as *Ammi*, *Cenolophium* and *Selinum*.

Seed germination

Germination is the process by which an otherwise quiescent and viable embryo begins and progresses through the sequence of events that cause it to develop and establish as a new plant. It occurs when a series of required environmental factors coincide and are satisfactory for the process to proceed. For the process of germination to be initiated and develop adequately, the seed will require exposure to an environment in which there is:

- Provision of a sufficient, non-limiting and suitable water supply
- An adequate and non-limiting atmosphere containing oxygen
- A suitable temperature regime
- Light (or lack of it if the seed is photosensitive) for photosynthetic activity, ultimately

Viable seeds that are exposed to the necessary environmental factors for germination and that still fail to germinate are said to be dormant. Germination, therefore, can only be achieved productively when this has been overcome by appropriate treatment with least loss of viability.

More detailed information and guidance on seed propagation, including overcoming seed dormancy, can be found in the publication ***Hardy Woody Plants From Seed***, by Phillip McMillan Browse.

Seed sowing in outdoor beds

Outdoor seed beds are mainly used by tree, forestry, rootstock and hedging producers but are also a useful technique for growing small quantities of rarer species. Easy germinating herbaceous subjects can also be sown outdoors.

Selecting the correct site

To ensure good germination and growth of seedlings, the soils and site for outdoor seed beds should be chosen carefully. The soil should be free draining but moisture retentive with a pH of 5.5–6.5 (towards the lower end for conifers and calcifuges). It should be of medium texture and conditioned with bulky organic matter prior to use for nutrition and moisture retention.

Poorly drained soils and low lying sites open to the elements should be avoided. The site itself should be well sheltered and, ideally, be of a warm, south-facing aspect to encourage prompt seed germination. Wind protection is especially important to protect seedlings from moisture loss and damage. Well-drained sites also enable prompt soil preparation and sowing in spring.

Seed bed sites should be of a warm, south-facing aspect, well sheltered and weed free

Rotation of seedling crops is also vital, to maintain the soil fertility and reduce the possible build-up of soil-borne pests (for example, nematodes) and disease pathogens (such as *Phytophthora* and *Verticillium*).

Site preparation

Land should be free of weeds, especially perennial weeds such as thistle, dock, bindweeds and couch grass; these must be eradicated well in advance of soil preparations. For residual weed control, the soil fumigant 'Basamid' (dazomet) is widely used, applied during the autumn for spring sowings and the summer period for autumn sown crops.

On heavy land, raised beds provide better drainage and are usually preferred, formed with a ridging plough. The bed sides are usually trimmed so they slope gently inwards, to form a bed around 1.5 m wide at the base and 1.2 m across the top. The height of the bed is usually around 15 cm. Beds should be levelled and firmed and base-dressed with a fertiliser in accordance with soil analyses. Soils that have been in production for some time may only require a light top-dressing of nitrogen, while new sites are often low in available phosphorus and potassium and so will require more. A final raking and firming should then be provided prior to sowing.

If the land is well drained and conditioned, then raised beds are not essential but, where Basamid is used, then the beds will be preformed by the tractor wheels, or the beds will be marked out with the tractor wheels when drilling seed. In practice, if the soil is well drained, beds that are raised actually tend to dry out faster and so can be detrimental.

Sowing

Seed sowings are usually made during April and May, sometimes a little earlier depending on the season and locality. Some subjects are best sown during the autumn period, especially those with short-term longevity, which deteriorate quickly if the seed begins to dry out. Subjects that usually respond better to autumn sowings include *Aesculus*, *Castanea* and *Quercus*.

Populus and *Salix* also have a short-term viability and these seeds are best collected fresh (as soon as ripe), and sown immediately.

Fraxinus excelsior can be sown 'green' (before the seed has ripened) but the resulting populations usually vary and cannot be guaranteed. Therefore, the seed is better treated and subjected to moist, warm conditions during the summer followed by cold stratification, as this enables the density produced to be more controlled. Treated seed is best sown early in the spring but can be cold stored until convenient and sown when the likelihood of frosts has gone so avoiding unnecessary work in providing protection.

Seed can either be broadcast over the bed surface or sown in drills; the latter enables easier hand weeding and thinning of seedlings. Sowing in drills also lends itself well to mechanical and chemical weed control.

Seed sowing in drills

While large scale sowings are usually mechanised, hand sowings will suffice for smaller and more varied seed lots. Seed sizes and sowing densities vary and hand sowing provides greater flexibility and control.

After sowing, the seed should be gently raked in, although in larger scale situations it is more usually lightly rolled into the surface to make contact with the soil and reduce the amount of material required for covering. When sowing direct into drills, the seed is either covered with the existing soil at the same time or covered with a material such as grit down the row; this approach uses very little covering material compared to broadcast sowings.

After broadcast sowing, seed are usually covered, generally with a fine, lime-free, grit or shingle, typically 1.5–4.5 mm size grade. The depth of covering depends on the size of the seeds but is normally around twice the depth of the seed (around 3 mm for small seeds and up to 12 mm for large seeds such as acorns).

Grit coverings are favoured as they provide good aeration, eliminate soil capping, enable easy removal of weeds and even percolation of rain or irrigation water. Perforated plastic films that lift and open as seedlings emerge can also be considered (after the seed has been covered) to encourage and protect new growth. Such films are widely used in the production of salad crops and field vegetables.

Each batch of seed should be labelled promptly after sowing with a waterproof marker pen. The label should record the full name of the subject sown, the date of sowing and source of the seed. It should also cross-reference with an office record of all sowings.

Where only modest quantities of seed are involved, this can be sown direct into prepared beds in cold frames to minimise losses. Such frames provide winter protection and summer shade.

Cultural work

Irrigation may be required after sowing, especially if conditions are warm and dry and the soil surface has dried out during preparation. Irrigation under these conditions will be required otherwise poor or uneven germination will occur.

Irrigation will also be essential throughout the spring and summer months during dry periods to enable germination to take place and to sustain seedling growth. Usually, irrigation is applied via overhead systems although low level systems such as lay-flat plastic can also be considered. Summer shading of seedlings is also necessary, especially with large-leaved subjects, during spells of hot, bright sunshine. Shade netting (1 m high) supported over the beds usually suffices.

Crop protection

Pest and disease control will require attention during the spring and summer period, notably for aphids and caterpillars, and damping-off and leaf diseases such as powdery mildew. Species should be grouped together at sowing to aid pest and disease control.

Mice can be a particular problem and seed taken over long periods, often with no visible signs of activity, can drastically reduce seedling populations. Mice and rabbits will also feed on emerging seedlings with possible bark feeding at the base in the autumn. Control measures need to be taken from the very beginning.

Birds can also devastate seed beds very quickly and some seed species are more susceptible than others (such as *Corylus avellana*, *Fagus sylvatica* and *Pinus* species). Damage is governed by the bird population and species in the area, coupled with availability of other food sources at the time. Larger birds, such as pigeons and pheasants, and smaller birds like finches tend to do most damage. Fleece or netting can be useful to protect crops.

Weed control will also require attention. Although the use of Basamid will reduce annual weeds during the first year; beds left down for two years will need some form of chemical or hand weeding to enable seedlings to develop unhindered. Currently, low rate use of Stomp Aqua (pendimethalin) and Goltix 70 SC (metamitron) can be used via off-label approval (EAMU) for residual weed control.

Powdery mildew on field-grown crops of *Acer*

Nutrition

A top-dressing of nitrogen may be required in midsummer to boost growth, depending on conditions and species. The frequency and type of fertiliser required throughout the growing period will be governed by species, size requirement, seasonal conditions and the degree of irrigation used.

Growth needs to be monitored, some species require more nutrition than others and grouping these together will also aid crop management. With the availability of irrigation, it is often better to feed little and often as this reduces the amount likely to be leached away. High potash feeds applied in late summer will help to harden plants off.

Undercutting

In order to improve the root structure of crops, particularly on mineral soils, seedlings grown on a bed system can be undercut mechanically in summer or autumn, using purposely designed equipment. However, this should not be done during lengthy dry periods, and adequate irrigation should be on hand if such conditions ensue following undercutting, otherwise, the crop will suffer and in extreme cases be lost. Crops that are intended to be grown one season in situ may be undercut once or twice during the growing season.

Some crops benefit from a very early undercutting when the plant is small and likely to have only produced a single tap root; this stimulates root development much earlier and at a higher level. Such plants would normally receive a further undercutting during the summer, below the previous depth but above the depth at which the crop will be lifted. Many crops may only be undercut once during the summer, producing what is sometimes referred to as a ½-u-½ plant – a one-year seedling that has been undercut.

Seedlings that will remain in situ for a further year would normally be undercut during late autumn or early winter when conditions are suitable, producing a 1-u-1 (two-year) seedling. When seasonal conditions are particularly favourable for growth, undercutting is also a useful crop management tool that can be used to check or slow growth down to regulate plant size. With plants that are to be planted or potted early (early autumn), undercutting 10–14 days before lifting will help stimulate new cell formation for enhanced root development and establishment.

Lifting

Seedlings can be lifted from autumn onwards following spring sowing, either en masse with an undercutter or selectively by hand with forks, after which they are transplanted or cold stored until required. Alternatively, they can be left in situ and grown on for a further year. Plants can quickly desiccate if left to dry out once lifted, particularly those still in green leaf and evergreen subjects. Particular care should be taken to avoid this happening via damping material down, keeping material out of full strong sunlight and transferring it promptly to cold storage.

Seed sowing under protection

A proportion of seed propagation is carried out under the protection of glass or polythene, for greater control and quicker throughput. Many herbaceous perennials, alpines and herbs, for example, are raised quite cheaply in this way. Some tree, shrub and hedging material is also produced in this way. Much of the work is now automated.

While more costly than outdoor or frame sowings, the benefits of greater predictability, enhanced uniformity and much speedier throughput often outweigh the additional costs. While low value, high volume crops can be produced readily and cheaply in outdoor seed beds, high value and tightly specified or scheduled crops require the closer control of indoor sowings.

Increasingly, seed raised crops are sown and grown in plug trays to ease and speed up handling and meet the rising demand for year-round sales and planting material. Although on a smaller scale, where low numbers are required, it is easier to sow into trays rather than into cells. Small seed, such as that of many herbaceous subjects, should be sieved prior to sowing to avoid any blockage of automated seeder units.

Many subjects, including herbaceous perennials, can be easily raised from seed and small numbers can be sown in trays

Growing media

Proprietary ready-mixed propagation media is often the preferred option for seed sowing direct into plug trays. Crucially, it must be well drained but moisture retentive, flowable and easy to handle. Such mixes are usually peat-based and comprise a wetter, lime for pH control, a low level base fertiliser (sufficient for balanced nutrition during the initial six weeks) and a short-term controlled release fertiliser in the form of mini-granules, to aid distribution in plug trays.

Vermiculite, being lightweight and sterile, is often included in seed propagation mixes too, largely on account of its useful buffering capacity. There is also some use of perlite to aid drainage and peat alternatives, notably coir and fine grade bark. Liner mixes can be used where seed is sown into pots. Longer-term, crops will require supplementary feeding to maintain quality.

Seed sowing

Many crops are now multi-seeded into pots or plug trays via an automated seeder unit. Although seed quality and viability are now much improved, it is vital that seed germination occurs in each pot or cell and produces a usable plant, hence, the practice of

Grit or vermiculite are widely used to cover seeds following sowing

It is also difficult to sow very small seeds singly by hand. Usually, the sown seeds are lightly covered with vermiculite or grit, to protect them and conserve moisture.

Young plant material for transplanting and growing on should be adequately hardened-off before transfer to unheated tunnels, glasshouses or outdoor nursery beds.

Many species are now directly sown into modules of various sizes; deep cells are especially suitable for trees

Environmental control

Seeded pots and trays should be transferred promptly to the protection of a propagation house or frame for germination. Many spring and summer sown HNS species usually require little by way of base heat, 15–18°C will often suffice where necessary, but will require a stable environment, including protection from extremes of temperature, light and moisture. To this effect, pots and trays are sometimes covered with a lightweight fleece or polythene propagation film, once they have been set down on beds or benches to create such an environment.

Supplementary lighting can also be used, for example, to accelerate the growth of winter or early spring sown seedling crops.

Trays and pots require regular checking to ensure they don't dry out or become overly wet. Any senescing foliage, which may attract *Botrytis,* should be removed promptly. Checks should also be made for early signs of damping-off, a fungal disease that thrives in the damp humid environments of propagation situations and any suspect seedlings removed immediately. Periodic venting by removing the covering film over pots and trays aids air movement and the dispersal of heavy condensation. It also enables any necessary fungicide sprays to be applied.

Once fully germinated, plant material should be gradually hardened-off inside before being transferred to a frame or sheltered outdoor bed for growing on. Early spring sowings may require fleece protection against late frosts.

Cuttings

A wide range of HNS species, including herbaceous perennials and alpine plants, can be raised successfully from various types of cuttings, including those made from sections of root. Cuttings are relatively simple to make and can be prepared and inserted by low cost labour if well supervised. In the case of hardwood cuttings, this can also be done during the quieter winter months.

Success with cuttings, especially those deemed to be slow or difficult to root, depends on:

- Optimum timing
- The type of plant material used
- How the material is handled
- The environment in which the cuttings are placed

Softwood and semi-ripe cuttings, especially of those subjects deemed slow or difficult to root, usually require a more supportive, high humidity propagation environment than easy rooting subjects or hardwood cuttings taken in the autumn and winter period.

Types of cuttings

Cuttings are usually categorised as follows:

- Stem cuttings. There are numerous different types of stem cuttings including nodal, internodal, heel and basal. The plant material can be softwood, greenwood, semi-ripe or hardwood, depending on when they are taken and the physiological condition of the wood
- Leaf and leaf-bud cuttings. These types of cuttings are usually formed from semi-ripe material
- Root cuttings. These are normally taken during the autumn to early spring period using dormant root sections

Many subjects can also be propagated by more than one of these methods, for example, *Camellia* (stem and leaf-bud cuttings) and many herbaceous perennials (stem and root cuttings). The chosen method often depends on the availability of suitable plant material; root cuttings, for example, are cheap and work well for some species but may be difficult to obtain in sufficient quantities. The available timeframe is another consideration; terminal semi-ripe shoot cuttings of *Camellia,* for example, will make a well-branched liner in six months, several months before one propagated from leaf-bud cuttings (typically, up to 12 months).

Stem cuttings

Stem cuttings (made from shoot tips and sections of stem) remain the most commercially important method of nursery stock propagation. Such propagation is generally from softwood and semi-ripe material. Stem cuttings can be nodal, internodal, heel or basal in origin depending on the growth and rooting characteristics of the subject and available material.

Nodal and internodal cuttings

Most cuttings are nodal in nature in that they are cut below the basal leaf joint during preparation, although many subjects also root well from internodal material, whereby the cutting is sectioned or cut between two leaf joints, so making greater use of available cutting material. Climbers (single node or leaf-bud cuttings of *Clematis* and *Hedera*) can be propagated in this way, as can Japanese maples (*Acer palmatum* cultivars) and many easy rooting subjects with long internodes such as *Buddleia* and *Hydrangea*. Often, both nodal and intermodal cuttings are prepared from the same length of stem material to make maximum use of available material.

Several cuttings can often be made from the same section of stem material

Close-up of typical nodal tip cutting

Close-up of a typical internodal cutting

Heel cuttings

Heel or heeled cuttings are made by removing a young shoot (usually semi-ripe) from its parent plant with a downward pull, bringing away on its base a small piece of older wood, which is then usually trimmed prior to insertion. It is debatable whether HNS subjects root any better with a heel but it can be a quick and easy way of removing cutting material from parent stock with minimal preparation. Removing the heel usually enables easier insertion and better anchorage of the cutting in the rooting medium.

Typical heel cutting, created by removing a young shoot from its parent

Basal cuttings (woody species)

Stem cuttings may also be basal in nature, whereby they are removed or prepared by cutting through or just below where a young shoot joins the main stem or parent branch. Usually, there is a slight swelling (pulvinus) at this point and the knife is taken through this or immediately below it, as, for example, when propagating fruit rootstocks by leafless winter cuttings. This also enables the cutting to be removed more easily from the parent plant. Such material is sometimes referred to as ‘grade 1’ because of its greater rooting potential.

Many other woody subjects propagate well from basal cuttings, notably cultivars of *Acer palmatum, Exochorda* and *Syringa*, especially when taken early, usually during April. *Berberis, Cotoneaster* and *Hebe* can also be propagated in a similar way when taken as semi-ripe basal cuttings during the summer or autumn period. *Cotinus,* too, responds well to soft, basal cuttings struck during June under mist or fog.

Close-up of a typical basal cutting; note the swollen base at the point of removal from the parent shoot

Often, subjects can be rooted equally well from nodal, heel and basal cuttings, for example, species and cultivars of evergreen *Berberis* taken in September and October.

Basal cuttings (herbaceous perennials)

The term basal cutting is also used to describe cuttings removed from the base of clump forming herbaceous perennials such as *Achillea*, *Aster*, *Delphinium* and *Phlox*. Usually, this material has a high propensity for rooting and so is especially useful for the propagation of subjects which are less inclined to root from softwood cuttings, including *Astrantia*, *Campanula lactiflora* and *Salvia nemorosa*. On some occasions, such basal cuttings come away from the parent plant with the roots intact, in effect forming mini-divisions rather than true cuttings.

Softwood cuttings

These are usually prepared from juvenile spring or early summer non-lignified (or ripened) growth of mainly deciduous but also some evergreen subjects during the April to June period. Typically, softwood cuttings are quite small, no more than 7–12 cm in length with two or more leaf joints (nodes); cuttings removed from shoot tips can be used for many subjects.

Propagation material harvested from stock plants or nursery crops should be removed just above a node to prevent die-back of 'stubs' and so in turn permit disease infection. A cut should be made below the node during cutting preparation for the same reason. The lower leaves are usually removed to facilitate easier insertion and subsequent support of the cuttings in the rooting medium (although this is not always necessary). Very large leaves should be reduced in size to minimise water loss and to maximise the number of cuttings per unit area. All flower buds should be removed.

Softwood cuttings are prone to rapid water loss and must be handled quickly and with particular care to avoid bruising and desiccation. The use of short term cold storage to remove 'field heat' and maintain turgidity is beneficial and improves the rooting potential.

Typical softwood cutting, trimmed to a node

HNS subjects widely propagated early in the season by softwood cuttings include *Acer palmatum* cultivars, *Azalea* (deciduous), *Cotinus*, *Exochorda*, *Magnolia*, *Prunus* (deciduous, notably *P. incisa* cultivars) and *Syringa*. Such material requires a particularly supportive environment and benefits from the use of mist or high humidity fog, with base heat for rapid rooting.

A wide range of herbaceous perennials, alpines and herbs, are propagated by softwood cuttings, including cultivars of *Achillea*, *Delphinium*, *Helenium*, *Helichrysum*, *Helianthemum*, *Lamium*, *Lavandula*, *Nepeta*, *Penstemon*, *Phlox*, *Rosmarinus*, *Santolina*, *Salvia*, *Scabiosa*, *Sedum spectabile* and *Veronica*. Typically, cuttings are quite short (5–7 cm) and removed from close to the crown of the plant. Such material can often be rooted readily at low cost under polythene or mist without base heat, direct stuck into plug trays of varying sizes. Adequate shading is essential during the summer months, particularly in the absence of mist.

While many subjects root readily and quickly from softwood cuttings without base heat, some of the slower and more difficult to root species do benefit from it. Initially between 18–21°C, reducing gradually as rooting occurs.

Although softwood cuttings are quite responsive to the use of hormone rooting treatments, easy rooting subjects seldom require them to root well. If considered necessary, low concentrations (0.1% IBA) should be used. Such treatments are likely to be more helpful for the rooting of later struck material if the basal areas have become ripened and a little woody, for example, with lavender and rosemary cuttings.

Similar remarks apply to wounding. While beneficial with firmer, semi-ripe material, particularly if having a woody base or taken with a heel of older wood, it is usually unnecessary and of little value with softwood cuttings.

Greenwood cuttings

Greenwood cuttings are taken when the stems are slightly firmer and darker, particularly around the basal area but not sufficiently firm to be deemed semi-ripe in nature. It is not a widely used term but is one that usefully indicates the idea that many subjects (including *Deutzia*, *Fuchsia*, *Hypericum*, *Philadelphus*, *Potentilla*, *Spiraea* and various herbaceous and alpine subjects) normally propagated by softwood cuttings also root well once the wood has gone beyond being soft. As such, they are taken slightly later than softwood cuttings, normally during the late spring to midsummer period.

Cuttings are usually nodal or basal in nature, formed from the current season's wood and typically 8–10 cm in length with three leaf joints. Soft tips are removed and the base of the cutting lightly wounded with a single slice (2.5 cm) to one side. Usually, a rooting hormone (0.1% IBA) is applied to the base and the foliage of very leafy cuttings reduced in size to minimise moisture loss.

Like softwood cuttings, greenwood material requires quite a supportive environment with high humidity to maintain freshness and reduce water loss; mist or fog environments are ideal. Base heat (around 18°C), while not essential, will aid rooting. Material should be shaded well during the summer.

Semi-ripe cuttings

Semi-ripe cuttings are made from partially lignified or ripened wood taken later in the season than softwood material, most usually from midsummer onwards using the current season's growth. To some degree, they are easier to handle and keep fresh than softwood cuttings and many broad-leaved shrubs and conifers are successfully propagated in this way.

Normally, cuttings are 7–15 cm in length and often wounded at the base to stimulate root initiation. They are sometimes removed from the parent plant with a heel of older wood, which is then trimmed with a sharp knife. The base of the cutting is usually quite firm and ripened.

Rooting hormone products are often used and very large leaves trimmed to reduce water loss and enable closer spacing of the prepared cuttings in their trays. There is usually some removal of the bottom leaves to facilitate easier and quicker insertion of the cuttings into the rooting medium. Shoot tips, stem sections and the basal portions of stems are used to make cuttings, with the basal cut usually being made below a node.

Typical semi-ripe cutting, trimmed to a node and slide wounded at the base

Leafy semi-ripe cuttings also require rooting under conditions that minimise water loss from leaves. A mist unit is ideal although polythene tent systems are commonly used, particularly for the autumn and winter rooting of evergreens and conifers. Close-contact polythene (thin gauge propagation film laid directly over cuttings) can be considered but must be carefully managed to ensure cuttings do not become too wet. It is a relatively cheap system that remains popular in the Netherlands.

For summer propagation, white plastic is required for shade, often augmented with shade cloth above, and in some cases, a shade paint applied to the roof of the glasshouse or polythene tunnel as well.

Semi-ripe cuttings of many HNS species can also be rooted easily and cheaply in sun tunnels or cold frames, either in beds formed from prepared soil or rooting media, or direct stuck into pots. These include cultivars of *Azalea* (evergreen), *Buddleia*, *Deutzia*, *Forsythia*, *Hypericum*, *Philadelphus*, *Potentilla*, species roses and *Spiraea*.

Softwood and semi-ripe cuttings taken in midsummer require rooting under conditions which reduce water stress

Hardwood cuttings

Hardwood cuttings are made from hardened or ripened wood generally taken from the current or sometimes the previous season's growth during the dormant period, normally between October and late February to early March. It is usually advisable to defer taking such cuttings of deciduous subjects until a few weeks after leaf fall because, up to that point, the stock plants are likely to contain high levels of abscisic acid, a naturally occurring plant hormone associated with leaf fall that is likely to inhibit root initiation.

For most trees and large shrubs, cuttings should be 20–30 cm in length, sometimes a little larger (up to 45 cm), for example, in the case of fruit tree rootstocks propagation to enable them to be budded clear of soil level and onto the original cutting.

Larger cuttings used to produce fruit tree rootstocks

Hardwood cuttings can also be used to root a range of conifers, including cultivars of *Taxus* and various species of *Abies*, *Juniperus*, *Picea*, *Pinus* and *Thuja*. Such material requires different propagation conditions to leafless winter cuttings, notably the provision of moisture to reduce water loss from leaves, hence, the use of polythene covers or mist. The latter can become too wet unless closely controlled.

Well-ripened wood of moderate size and vigour should be used to ensure the cuttings have adequate food reserves in the form of carbohydrates to sustain root development and in turn initial shoot growth. Shoot tips are usually discarded; central and basal stem sections make the best cuttings. Normally, the cuttings comprise straight stem sections of usually one-year-old wood.

Leafless hardwood cutting comprising ripened wood taken during the dormant period

Hardwood cuttings of both deciduous and coniferous subjects are usually wounded at the base to varying degrees and treated with a rooting hormone to help initiate roots. *Taxus* appear to root best when taken with a heel of ripened wood from the parent plant and when inserted into well-drained rooting media with sharp sand or grit.

Hardwood cuttings can be rooted with or without base heat, depending upon species and available facilities. Heated cutting bins are sometimes used for more difficult to root subjects, including fruit tree rootstocks. Many subjects can be rooted with heated benches or beds, including: *Akebia trifoliata*, *Celastrus orbiculatus*, *Cytisus battandieri*, *Ficus carica*, *Fuchsia magellanica*, *Lonicera* species, *Metasequoia glyptostroboides*, *Parthenocissus*, *Polygonum baldschuanicum*, *Vitis coignetiae*, *Wisteria sinensis* and *Wisteria floribunda.*

Usually, basal temperatures of 18–21°C suffice but the tops of the cuttings need to be kept relatively cool (frost-free or just above) and dry with plenty of natural daylight, not subject to mist or covered with polythene. If the air temperature is too warm, bud burst and shoot growth will ensue at the expense of rooting and the cuttings will perish.

Rooting normally occurs within six to eight weeks. Cuttings can be inserted into deep plug trays or pots, larger cuttings can be inserted around the edge of a 2-litre pot. Biodegradable pots such as those formed from peat, coir or recycled paper can also be considered to minimise root disturbance and waste disposal.

For smaller shrubs and climbers, cuttings are usually nodal, 15–20 cm in length and inserted to about a third or a half of their length. They should be kept well aired and the rooting medium moist but not wet.

Rooted cuttings can be spring potted and grown on under protection before being moved outdoors during the summer.

Hardwood cuttings of many woody subjects can also be rooted cold, either in the open ground, under sun tunnels or using traditional cold frames. Bush fruits such as blackcurrant and gooseberry, for example, root readily in field situations, as do other easy rooting species like *Ligustrum*, *Populus* and *Salix*, for hedging and species roses for rootstock production.

Shrub subjects such as *Buddleia*, *Cornus*, *Deutzia*, *Forsythia*, *Philadelphus*, *Ribes*, *Sambucus*, *Spiraea* and *Weigela* can be rooted with the simple protection of a cold frame. Principal requirements are good drainage, natural light and adequate air movement to ensure cuttings don't rot and attract disease pathogens such as *Botrytis* around the stems or *Phytophthora* in the roots.

Leaf-bud cuttings

Although not widely used commercially, leaf-bud cuttings are useful for the late summer and autumn propagation of some HNS subjects, for example, *Mahonia* where the morphology of the plant precludes the use of stem cuttings and *Camellia* where leaf-bud cuttings are useful if propagation material is quite scarce. Only strong shoots with well-developed buds should be used. Such cuttings comprise a short section of main stem cut just above a leaf joint and again between two nodes, resulting in a single leaf attached to the stem with a leaf-bud in the axil.

Leaf-bud cuttings make efficient use of propagation material

Semi-ripe wood is usually lightly wounded and, while rooting hormones can be applied, any treatment should be used with particular care due to the proximity of the buds that can be damaged or their growth delayed.

Some climbers, notably species and cultivars of *Clematis* are also propagated successfully from internodal leaf-bud or single node cuttings during spring and summer under mist or plastic with base heat.

Root cuttings

Many subjects can be propagated cheaply and efficiently by sections of root taken from healthy vigorously growing stock plants or nursery crops during the autumn and winter, making saleable plants within 12–18 months. Notable examples include *Acanthus*, *Ailanthus*, *Campsis*, *Clerodendron*, *Echinops*, *Eryngium*, *Paulownia tomentosa*, *Phlox paniculata*, *Rhus typhina*, *Romneya coulteri* and *Verbascum*. Comparatively unskilled labour can be used to prepare and insert the cuttings if well supervised. Rooting percentages are typically high, up to 75%.

Roots of pencil thickness should be selected where possible or slightly thicker for those subjects with especially thick roots such as *Eryngium* and *Rhus typhina*. It is often easiest to remove longer lengths of root material and cut these into the desired length on a bench with a sharp knife. Sufficient root should be left to enable stock plants to re-establish quickly.

The roots of thick rooted subjects are usually cut into sections around 5 cm in length. Unlike thin roots, they are usually inserted vertically and pushed into the rooting medium until their tops are just below the surface. To ensure the cuttings are inserted the correct way up, a sloping cut should be made at the top or proximal end and a flat cut at the bottom or distal end; the top of a root cutting is always that part that is nearest the stem of the stock plant. Cuttings should be spaced around 7 cm apart or inserted singly into plug trays.

Thin roots are simply cut into 5 cm sections and laid horizontally on the surface of the rooting medium before being covered, usually with a 1–2 cm layer of the medium mix.

Thin roots are laid horizontally on the surface of the rooting medium and covered over with the medium or grit

Cuttings can be directly stuck into beds, trays, plug trays or pots of standard rooting media and propagated in cold frames or a dry, frost-free location under glass or polythene. Good medium drainage is critical and while base heat (12–15°C) is not essential, it will accelerate root development and help to minimise losses, as in the case with *Romneya* and *Verbascum*. Cuttings are usually covered with a lightweight fleece or plastic to conserve moisture and retain heat.

Usually, rooted material is removed from May onwards by which time the cuttings should have formed new roots and be growing away. Rooted material should be moved on as soon as it has formed satisfactory root systems. However, care is required, as root cuttings, especially those in warm conditions, often produce top growth before they have rooted adequately. Once roots do emerge from the bottom of pots or trays, the plants should be potted and grown on. Those raised in heat will require hardening off in tunnels or a cool glasshouse first.

Acanthus growing away in summer, following early spring propagation by root cuttings direct stuck into plug trays

Callus tissue

Often the rooting of mainly semi-ripe cuttings is preceded by the quite visible formation of wound or callus tissue. While this is a wound healer and natural precursor to root initiation, excessive callus inhibits rooting. High base temperatures can trigger this problem.

Excess aeration in the rooting medium may also stimulate callus at the expense of root initiation (commonly seen in *Camellia*, *X Cupressocyparis* leylandii and *Taxus* species, for example), underlining the value of striking the right balance between drainage and moisture retention. Alkaline conditions in the rooting media exacerbate the problem by hardening the cells walls in the outer layer, so making it very difficult for young roots to penetrate. For plant material in very free draining rooting media under open mist systems and irrigated with alkaline (hard) water, this can be a particular problem as the pH of the rooting medium rises.

Excess callus formation is also caused by using cutting material which is physiologically underdeveloped for rooting. This underlines the importance of timing, particularly in respect of softwood and semi-ripe cuttings.

Micropropagation

Micropropagation is the isolation and culturing of small sections of plant tissue (an explant) in a sterile, carefully controlled environment. Usually, these are meristematic tips but material may also be pollen, embryos or callus. It is a highly specialised technique developed commercially during the 1960s for the production of virus-free plant material, primarily *Cymbidium* orchids and later fruit rootstocks, strawberries and *Narcissus* using meristem tip cuttings.

Since then, the range of HNS species that can be successfully micropropagated by specialist suppliers has increased dramatically and many species can now be produced in this way. These include *Alnus*, *Arbutus*, *Azalea*, *Betula*, *Buddleia*, *Clematis*, *Cordyline*, *Cornus*, *Cotinus*, *Daphne*, *Eucalyptus*, *Garrya*, *Hamamelis*, *Hebe*, *Hydrangea*, *Kalmia*, *Lavandula*, *Magnolia*, *Malus*, *Photinia Pieris*, *Potentilla*, *Prunus*, *Rhododendron* (notably, difficult to root *Yakushimanum* hybrids), *Rosa*, *Rubus*, *Skimmia*, *Syringa*, *Ulmus* and *Viburnum*.

An increasing range of herbaceous perennials can also be raised by micropropagation, including cultivars of *Bergenia*, *Campanula*, *Cimicifuga*, *Crocosmia*, *Digitalis*, *Echinacea*, *Geranium*, *Helleborus*, *Heuchera*, *Hosta*, *Kniphofia*, *Leucanthemum*, *Lobelia*, *Nemesia*, *Papaver*, *Phlox* and *Scabiosa*. It can also be used for the propagation of *Anemone japonica* cultivars to ensure freedom from leaf-bud nematode, a frequently common and serious pest of this plant.

Several important bulb crops can also be raised this way, including *Anemone*, hyacinth, *Iris*, lily, *Narcissus*, *Nerine*, snowdrop and tulip, although in most cases only to increase breeding stock.

Almost any plant can be micropropagated with some development work but the efficiency of production varies considerably so a more limited range is economically viable and commercially available.

The principal advantages of micropropagation are:

- The rapid clonal multiplication and so bulking up of slow or difficult to root species and new cultivars
- The production and maintenance of high-quality, uniform, clean, virus-free plant material
- Year-round propagation of an increasingly wide zrange of plants suitable for scheduled production for continuity of supply

Micropropagation also enables a large number of plants to be handled and transported at any one time, although this must be done carefully, as should the weaning of such material prior to growing on under nursery conditions. The hygienic soil-less nature of the production process also means micropropagated material can be exported easier than plants grown by more conventional means.

Micropropagated plants can be easily transported and exported, once weaned, as well, and this is often a more foolproof way for growers to receive material.

The process is very specialist, skilled work and can be difficult to integrate with the rest of the nursery. It also requires significant capital to establish the requisite laboratory and weaning facilities; even a small laboratory requires significant specialist equipment costing £50,000–100,000. Labour costs can also be high, up to 80% of the total running costs and vary considerably depending on the plant being propagated. Including labour for bulking-up, overall production is, typically, 25–50 plants per hour.

Micropropagation is now used for the rapid multiplication of a wide range of HNS subjects

Genetic mutations or 'off-types' may also occur (as they can with conventional techniques) although this is much more likely to arise from callus cultures than where shoot cultures are used to multiply material. For this reason, callus cultures are avoided in commercial micropropagation. Not all plants respond to micropropagation either and so must be increased by conventional means, which may take longer and be confined to specific time periods.

For these reasons, micropropagation in the UK is now undertaken by specialist producers with the necessary expertise, facilities and equipment for commercial success.

Culture medium

Usually, the culture medium comprises mineral salts for essential macro and micro elements, an energy source (usually in the form of sucrose), amino acids, vitamins and growth hormones (notably, cytokinins for shoot formation and multiplication and auxins for root initiation) and agar (gelling agent) for support.

The balance of these elements within a medium varies with species and can vary between cultivars within species. Micropropagation specialists tend to formulate their own media based on experience and the differing requirements of the species involved but a limited range of 'ready-to-use' standard media are available.

Equipment

Sterile conditions are essential to prevent infections of bacteria or fungi, in the culture medium. All preparation work is done in a laboratory and is carried out under aseptic conditions, using laminar airflow cabinets in order to exclude contaminants.

The standard equipment required for tissue culture includes glassware, culture vessels and an autoclave for sterilisation of tools and culture media. Scalpels, sharp scissors, knives and forceps are used to handle, divide the cultures and prepare the propagules. Flame sterilisation or hot glass bead sterilisers are used for their sterilisation.

Prepared material is placed in jars or tubs on the culture medium in an incubator, growth cabinet or growing room to grow at a constant temperature, usually in the region of 20–25°C for most HNS species. Light is less critical at this stage and incubators are often only lit by a single fluorescent tube per shelf, giving a low light intensity.

Stages of micropropagation

The process of micropropagation usually comprises five stages, these are summarised below:

Stage 0 – stock plant management

For success, only high-quality clonal stock plants, which are true to type and of high health status, should be used for the provision of propagation material. Stock plants should be grown under clean, hygienic conditions and material should be taken at the correct time, that is when the plants are actively growing. Usually, container-grown plants are used and brought under protection prior to propagation, to produce clean, fresh, vigorous, juvenile material suitable for micropropagation. Ideally, they should be watered by low-level irrigation as water splash from overhead systems can readily increase the fungal and bacteria growth always present on plant surfaces.

Stage 1 – initiation

This stage consists of the establishment of plant material in culture. Ensuring freedom from contamination at this stage is critical, therefore careful surface cleaning and sterilisation is essential. Exposure times have to be carefully worked out to minimise damage to the explant material. Only 50%, and often less, of the material initiated will be clean enough to take to stage 2.

Stage 2 – multiplication

The rapid increase of material occurs at this stage, as the cultured material grows rapidly and produces new shoots, which are routinely divided and transferred to fresh media for further multiplication (sub-culturing). Material is grown on in a growth chamber until the required quantity has been obtained. High light levels are not required as micropropagated plants do not photosynthesise greatly at this stage, depending instead on the sugars and nutrients in the media for new growth and root development.

The multiplication process rapidly builds up plant numbers

Stage 3 – rooting

Small shoots are excised and transferred singly to a fresh culture media to induce roots. Usually, this involves manipulating the hormone balance; high auxin to cytokinin favouring root development, high cytokinin to auxin favouring shoot production. This stage usually takes place in a growth chamber or growing room. In some species, it can be omitted and shoots produced in culture, treated instead as soft cuttings and inserted into a rooting medium with root initiation occurring during weaning.

Stage 4 – weaning

Weaning is the establishment of plantlets in growing media following multiplication in culture. When rooted, they are transferred to small pots or plug trays to establish. This stage can be the most difficult and requires a supportive, high humidity environment to ensure material does not dry out. The lack of a waxy leaf cuticle on micropropagated material (along with leaf stomata being frequently locked open) means moisture is lost much more readily than with conventionally raised plants.

It is equally important not to over water at this stage, otherwise material will quickly deteriorate and become susceptible to disease infection, notably *Botrytis* and damping-off. Shade and adequate base heat provision are also required. Usually, this initial weaning period lasts for around two weeks, after which the plantlets are transferred to a more open glasshouse or polythene tunnel for further weaning before being hardened off for potting and grown on as liners or sold as weaned plantlets.

As a guide, HNS species usually require in total a gradual weaning period of at least one month before being subjected to a regular nursery environment and a further period of two to three months of growing and hardening off before potting.

Practical aspects of working with micropropagated material

In laboratory situations, growing rooms are generally neither suitable nor cost-effective for weaning and plantlets need to come out of their laboratory environment into gradually more natural conditions at some stage. Deciding when is the key, because while initiation and sub-culturing are for the most part year-round techniques, rooting and especially weaning are more closely aligned to the natural seasons. This is particularly so with hardy woody plants and especially deciduous species, which enter dormancy as the day length shortens and ambient temperatures reduce. Plants not at the right stage of development will struggle to overwinter.

To wean micropropagated plants during the winter months and even early spring, which is a good time to wean in terms of supplying plants for potting later in the season, it will be necessary to use supplementary lighting.

Critical to weaning success is for the propagules to have been given an adequate rooting period after sub-culturing (if one is required); ideally, this should be done in a separate growing room as the requisite temperatures often differ from those of the early stages. The priority is to initiate adequate roots on each plantlet before the initial weaning process starts. Using a separate compartment also enables light levels to be gradually increased to harden the plant, notably by enabling the leaf cuticle to develop greater protection.

Micropropagated plantlets have a particular anatomy, often characterised by quite thin leaves from which the normal waxy cuticle is largely absent and with frequently open stomata. Maintaining a high relative humidity around the plants is therefore crucial, particularly during weaning. Even during the transplanting process, leaves can become flaccid and very easily damaged by water loss.

Grading is important throughout micropropagation, otherwise mixed batches will complicate crop management, not least with the movement of plantlets of varying sizes and stages of development through the different stages of the process.

Although most nurseries now buy in their micropropagation requirements from specialist producers as rooted cuttings or weaned plantlets in plug trays ready to grow on, they must still be handled with great care during this critical phase, to ensure the young plants neither dry out nor become overly wet. Nurseries receiving hardened plants should ensure they have been fully weaned before delivery.

Very young plant material (especially stage 3 but also stage 4 if semi-weaned) requires particularly careful handling following delivery and prior to potting on. It should, therefore, be given a supportive high humidity environment such as that provided by fog, polythene tents or mist units to ensure material does not deteriorate.

High humidity environments must be well controlled, as it is particularly important not to over wet the plants. Well-managed fog systems usually strike the right balance and maintain a high humidity without creating very wet conditions. Mist can sit too wet and tent systems require especially careful attention, although they are the cheapest method. Slit films can be considered for hardier HNS subjects.

Semi-weaned plantlets require a supportive environment until established, fleece tents maintain the necessary humidity

Another critical aspect during weaning is the provision of adequate shade from hot, bright sunshine to reduce water loss and in turn deterioration of young plantlets. Milky polythene should be used for tent systems and shading for glasshouses where mist or fog is preferred, although the latter tends to produce its own shade. Additional net shading used and removed in accordance with prevailing conditions may also be required. In summer, 80% shade may be needed.

Stage 4 plant material, if fully weaned and hardened, will only require a little care with watering.

Adequate nutrition is also important throughout weaning, especially with plug trays. Liquid feeding provides flexibility, although low rate mini granule controlled release fertilisers can be considered.

A batch of micropropagated *Heuchera*, fully weaned

Improving liner growth and quality post-weaning

While most micropropagated material grows away successfully on the nursery following weaning, some crops can pose particular problems. In the case of *Kalmia* and *Betula,* premature dormancy can occur during the growing season when environmental conditions are suitable for growth, while with *Daphne* poor branching can lead to misshapen plants.

Betula plants can enter premature dormancy if subjected to a period of cold growing conditions; so care needs to be taken to avoid late spring cold spells. This dormancy can only be broken by a cold treatment of six weeks at 4°C.

Daphne odora 'Aureomarginata' and *Daphne cneorum* are naturally slow to branch (usually, this occurs post-flowering) and often do this higher up the stem, creating an unbalanced appearance, less attractive for sales.

AHDB Horticulture project HNS 32: ***Factors controlling the quality of micropropagated HNS liners***, sought to better understand the factors responsible for poor liner growth following weaning, using *Kalmia* and *Daphne* as examples of such problems. The work focused on both the procedures adopted during micropropagation and how these may affect subsequent growth, and the nursery practices that could be adopted following micropropagation to improve growth.

Overcoming premature dormancy

The following were key findings for *Kalmia* from the project:

- Maintaining shoot growth by early and regular liquid feeding, increasing the frequency as the plant develops and is potted on, helps overcome premature dormancy
- Using supplementary heating over winter helps to boost subsequent growth and branching of liners when combined with liquid feeding
- Premature dormancy during the growing season may be broken by subjecting liners to four weeks chilling at 4°C

Improving lateral branching

In the case of *Daphne*:

- Shoot production and lateral development may be induced during micropropagation but at the expense of rooting and plant vigour during early establishment. *Daphne* species are very sensitive to cytokinin concentration and may require different concentrations to achieve the right balance; different types of agar may also promote further variation
- Growing young plants over winter with heating and supplementary lighting promotes better branching and more early flowering. Recently weaned plants are more responsive than older ones
- Pruning weaned material creates a lower framework but should be done when plants are dormant, so that apical dominance doesn't restrict branching, timing is crucial. While *Daphne cneorum* cultivars can be pruned in this way once well rooted, subsequent vigour and establishment may suffer, so pruning in early spring is more appropriate

These findings are likely to have broader applications to other crops that display premature dormancy or a lack of early branching.

Case study 3: Micropropagation Services (EM) Ltd

Micropropagation – a view from the laboratory

Neal and Barbara Wright set up Micropropagation Services Ltd near Loughborough, in Leicestershire, in 1985. The family-owned business is now one of the UK's leading suppliers of young plants, producing over a million each year, mainly from micropropagation but also from seed and cuttings.

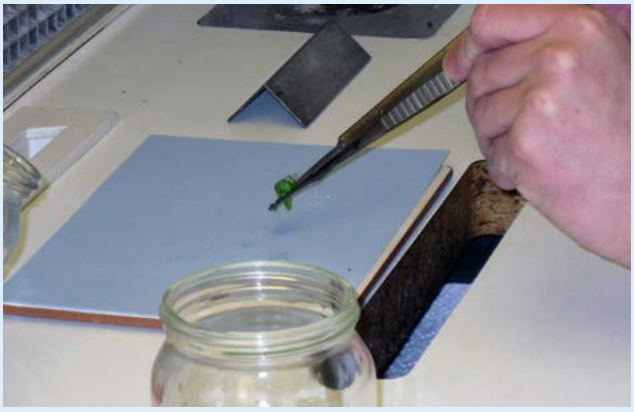
The plant range produced includes shrubs, roses, climbers, ericaceous subjects, blueberries, herbaceous perennials and trees for amenity and woodland situations. Popular lines include ground cover roses, herbaceous perennials and *Betula jacquemontii*. Graded, fully weaned (stage 4) plants are despatched to customers in preformed Elle pots.

Director Neal Wright summarises the business: "Increasingly, we see ourselves as a complete young plant supplier as distinct from a purely lab-driven one. As the business has evolved, it has become clear to us that, to be viable and competitive, we need to be flexible and not focus purely on micropropagation. In many ways, micropropagation and conventional techniques mesh together very well, requiring similar, protected growing environments that are well controlled. However, for this to work, the laboratory and nursery functions have to be well integrated. It must also be forward planned and well organised; micropropagation attracts high labour costs, so efficient working is important.

"Thorough weaning is crucial too. We prefer to despatch stage 4 rather than stage 3 material as the latter is more vulnerable and so more difficult for growers to handle. Some HNS subjects wean easier than others, for example, herbaceous perennials are usually quite straightforward, while most of the woody species can be quite difficult. We use supplementary lighting for winter and early spring weaning.

"Most of our propagation occurs during the spring and summer periods, when stock is in active growth, with crops weaned and overwintered for spring and summer sales the following year."

For crop protection, the nursery prefers to use biopesticides such as Serenade ASO, for example, to control *Botrytis* and Met 52 for vine weevil control. Good cultural practice, including maintaining high levels of nursery hygiene are also important. Drench treatments of the microbial inoculant products Revive and Trianum are also used to help prevent root diseases and stimulate growth. Neal continues: "Our customers require reassurance about vine weevil control so we incorporate products to deal with it. We also use a bespoke growing media (75:25 peat to bark with base and controlled release fertiliser) and make our own Elle pots to give us added flexibility and quality control."



Plant multiplication under way

Improving the quality of HNS plants raised by micropropagation via pinching

The quality of finished plants is often influenced by pinching or pruning treatments applied to weaned plantlets and liners before potting on. AHDB Horticulture project HNS 40a: ***Optimising pruning of micropropagated and conventionally propagated container-grown plants***, looked at the effect of different pinching treatments on micropropagated *Rhododendron*.

Treatments included early or late pinching (removal of the growing point and top 2–3 leaves) of weaned plantlets in plug trays or a pinch after potting on.

The work with micropropagated material focused on cultivars of *Rhododendron yakushimanum* ('Percy Wiseman', 'Titian Beauty', 'Sleepy', 'Hoppy', 'Venetian Chimes' and 'Silver Sixpence') and a single hardy hybrid ('Pink Pearl').

Treatment effects varied with cultivar, which in terms of response could be broadly characterised as follows:

- Those that branch naturally and require little if any pinching either in the plug tray or after potting, e.g. 'Titian Beauty'
- Those that require pinching, in the tray to stimulate branching, e.g. 'Percy Wiseman'
- Those that require pinching in the tray and after potting to develop a good branch framework, e.g. 'Pink Pearl'

The *Rhododendron yakushimanum* hybrids tended to branch more freely than the more vigorous hardy hybrids. An early pinch in the plug tray appeared especially important in encouraging branching of the *Rhododendron yakushimanum* hybrids. Some improvement in branching of the hardy hybrid 'Pink Pearl' was achieved by a double pinch.

Case study 4: Seiont Nurseries

Micropropagation – a view from the nursery

Seiont Nurseries near Caernarfon in Wales produces 1.2 million young plants a year, comprising 300,000 plugs and 900,000 pot liners, divided equally between herbaceous perennials (notably, *Agapanthus*, *Hosta* and *Heuchera*) and various shrubs (mainly *Physocarpus*, *Sambucus* and *Sorbaria*).

The nursery had considered using a high humidity fog environment to wean micropropagated material (usually bought in as stage 3 rooted cuttings for pricking out or stage 4 weaned plantlets for liner potting) but opted for mist, managed carefully with the expertise of experienced staff. Fleece, as a temporary tunnel cover over pricked-out stage 3 micropropagated material, provides shade and reduces water stress on the young plants. Once bulked up by micropropagation, new lines are usually propagated by conventional cuttings.

Varieties that are difficult to wean such as *Heuchera* 'Midnight Rose' are bought in as a stage 4 weaned plantlet to ease establishment. "Our usual drill with stage 3 material," says Neil Alcock, Nursery Manager, "is following pricking out into plug trays (40% coir, 30% peat, the balance comprising vermiculite and perlite), the young plants are misted and covered with fleece. A half-rate fungicide is used to protect young plants from disease infection while they are establishing."

Neil goes on to mention that successful weaning means "planning your production so that propagation material is not all arriving at the same time, especially micropropagated material. Schedule receipt of deliveries early in the week where possible. Wean tricky varieties in highly visible nursery locations to help monitoring. Get micropropagated plants pricked out into plugs as soon as they arrive on the nursery. Don't let them hang around; the transport of stage 3 material is damaging enough, they are using up reserves all the time. Wean large batches of micropropagated material in spring rather than during the heat of midsummer."

Well-rooted weaned plantlets of *Heuchera*

Grafting and budding

Grafting and budding techniques are fundamentally the same procedure, namely that of joining a scion variety to a compatible rootstock; so much so, that the term grafting often includes budding. Individual cultivars can be propagated by either or both techniques depending on the time of year (dormant or growing season), method, environmental conditions and materials. There are no hard and fast rules and individual nurserymen have developed many minor variations on the basic principles described below. Both methods are vegetative propagation techniques, used where other propagation methods are less successful or uneconomical.

Pioneering work in the UK at NIAB EMR and Long Ashton Research Stations between 1940 and 1990 introduced new selections of rootstocks for fruit trees that provided a wide vigour range, including the release of the first virus-free material of both rootstock and scion varieties. Further work was to continue, with some clonal rootstock selection of *Acer platanoides* and *Tilia cordata* amenity rootstocks, and the very successful commercialisation of 'chip' budding that now dominates fruit and ornamental field production in many countries.

Grafting can be used both in the open ground and under protection at various times of the year for the more difficult subjects, while budding is generally used in field production during the growing season, on relatively easy subjects and where propagation speed and economic use of propagation material are a priority.

All grafting and budding methods share the same principle of uniting the cambium layer of scion and rootstock accurately to form a strong union. Compatibility of scion and rootstock is vitally important. There are numerous simple and quite intricate grafting techniques and the most common and effective of those used in modern propagation are described in this section.

There are several economic and practical reasons for grafting or budding, notably:

- It is an important technique for plants that will not root well from cuttings. Rootstocks have a well-developed fibrous root system to quickly support the rapid formation of callus between rootstock and scion, eliminating the loss potential of other rooting techniques
- It enables saleable plants to be produced more quickly. The rapid growth that results from the carbohydrate reserves in rootstocks produces vigorous straight stems and maximum girth early in the tree production cycle
- It helps control plant vigour. In particular, for dwarf fruit trees in modern orchards and gardens, where vegetative growth is reduced and fruit productivity is increased at the same time. Low vigour rootstocks for *Malus* and *Prunus* are now being considered for amenity use to reduce the size of trees in urban street planting
- It is useful where special growth forms are required, as in, for example, the top-working of standard or weeping trees and, conversely, the production of dwarf plants
- It can promote earlier flowering. Dwarf fruit rootstocks in particular have an influence on the formation of early fruit bud
- It is a useful nursery technique for spreading workloads. With the use of cold storage to extend dormancy of both scion and rootstock, nurseries are now able to spread out their propagation programme

In terms of the equipment required for grafting and budding, make sure good quality knives made of hard steel are used and are sharpened to a keen edge. As grafting is a form of precise carpentry, the very sharpest of blades will make all grafting motions easier and result in smooth cut surfaces for quick and healthy callus formation. It is best to finish the sharpening of the blade on a leather strop to ensure the sharpest of edges.

Various hand and power assisted grafting machines have been created; most are quite useful if scion and rootstock match exactly. However, in reality, this match is difficult to achieve so the skill of the knifeman is the key to a good 'take'.

As for knives, secateurs need to be clean, sharp and well maintained.

A selection of knives used for budding and grafting, the top two are used for 'T' or chip budding, the curved blades for grafting large calibre rootstocks and scion wood, while the bottom three are suitable for bench and rind grafting

Tying materials, the methods used and the timing of removal

Tying materials come in either degradable or non-degradable forms. Degradable rubber of many differing widths and grades can be used, including 'patches' specifically manufactured for rose budding that are held in place with a wire staple. In general, strips or rolls where material is self-selected by length are the most common tying materials for grafting and chip budding. Degradable ties are convenient and recommended for the easier subjects.

Bud patches made from degradable rubber are normally used when 'T' budding roses

Non-degradable polythene and now more modern stretchable self release laboratory materials are all used by nurserymen. Non-degradable ties are reliable as they can be released at a given time and offer the propagator precise control during the crucial weaning-off period.

Non-degradable polythene budding tape is widely used when chip budding and provides control during the critical weaning-off period

All tying methods have the same golden rule, to be firm enough to stop any water penetration and to encourage callus quickly but not to be too firm so as to constrict growth.

The removal of non-degradable ties should take place once callus has formed, usually after approximately 4–6 weeks and before any constriction takes place due to expansion of the rootstock. It is also necessary to be aware of fungal infections that may develop beneath the tie if they remain in place too long. If removing ties with a sharp blade, the bark must not be injured in any way and it is best to cut away from the stem.

Wax and waxing equipment

Cold and hot waxes are useful to cover the graft union where rubber ties are used and for sealing the scion top cut surface or as a dipping wax for the whole graft. The latter requires a hot water heater complete with an accurate thermostat. It is recommended that wax temperatures do not exceed 75°C. Wax comes in many purpose made preparations based on paraffin waxes, with additional softeners and occasional fungicides.

Equipment hygiene

This will be discussed in general terms throughout this section but regular sterilisation of the cutting surface of knives and secateurs prevents the spread of harmful pathogens. Methylated spirits, weak solutions of domestic sterilants or other preparatory products are examples.

Rootstocks

Sources and age of rootstocks

Specialist rootstock growers are a good source for a wide range of seedling and clonal rootstocks. Certain selected seed sources are usually earmarked |for rootstocks and it is important to discuss the options with the supplying nursery. Depending on the propagators preference, either one year or two year-old rootstocks are used. Universal coding in trade catalogues is useful to know and the following are used:

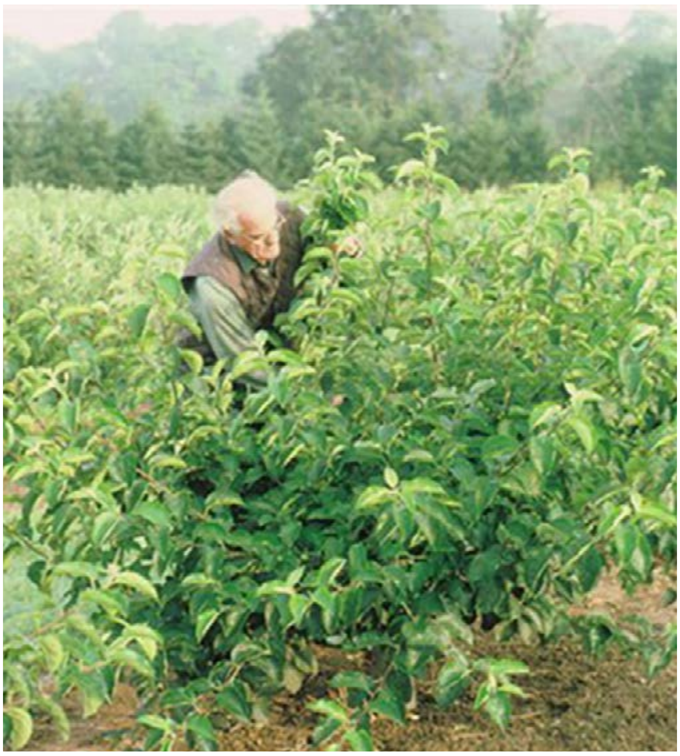
- 1+0 (1 year)
- 1+1 (1 year then transplanted for a further year)
- 1-u-1 (2 year undercut but left in situ for the second year)
- 1+2 (1 year transplanted and grown on for 2 years)
- 2+0 (1 year)
- 2+1 (2 year then transplanted for a further year)

The above codes cover both seedlings and clonal rootstocks grown from layers or stool beds.

Rootstock grades

It is important to know the particular grade (girth) that is required for the type of graft to be employed. For the purposes of field budding a planting grade of 5–7 mm or 7–9 mm is ideal, with the expectation that at the time of budding this rootstock will be in the region of 8–12 mm to match suitable bud wood.

Potted rootstocks of *Acer palmatum* cleaned and ready for grafting



Well-managed stock plants enable large quantities of scion wood to be harvested at the optimum time

A knowledge of the preferred pot size and the expected growth rate is important to judge the size of the rootstock to be purchased if pot-grown rootstocks are to be used for winter or summer grafting after one growing season. Bare-root grafting is easier to service by ordering the exact calibre of stock required. Scion wood can be extreme, from that of the very thin *Acer palmatum* material used for summer grafting to much broader *Aesculus* material used for winter bare-root bench grafting.

Clonal rootstocks

The advantageous properties of clonal rootstocks have been mentioned earlier and they should always be considered in preference to seedling raised material where available, not only for increasing the success rates in grafting but to improve the uniformity of growth in the nursery.

Scion wood

Knowledge of the progeny of the parent material, its confirmed identity and the accuracy of labelling and records are all important before the collection of scion wood (or bud wood in terms of budding material) begins.

Sources of material

It is quite acceptable to take scion wood from saleable production trees or shrubs as it is very often healthy and juvenile. All scion wood should be of one-year-old material (of current season's growth).

However, there are many advantages of having established stock plants. Large quantities of scion wood can be harvested efficiently at the right time and in a dedicated stock area.

Health status

Pests, diseases and virus infections can all be transferred during the multiplication process, so vigilance is required to maintain clean stock material. Close visual inspections should be ongoing throughout the dormant and growing seasons with additional laboratory testing to confirm any suspicious symptoms. Modern molecular tests are now available for basic virus infections and batch tests can be done quite economically.

Collection and storage

All budding and grafting success rates are maximised if scion wood is collected swiftly, kept cold (3–4°C) and well watered to maintain moisture levels.

Soft shoot tips and mature basal stem areas should be discarded and, in the case of scion wood, leaves on the remaining section trimmed to leave short petioles. Usually, the bud sticks are then bundled and labelled until required.

For summer grafting, some propagators prefer to retain some leaves on the scion wood if a covered grafting case of some sort is to be used. Maintaining the grafts in a moistened state is essential.

For winter grafting, the same cold store temperatures (3–4°C) should be used and scion wood should be wrapped to prevent desiccation. It is advisable to collect scion wood from mid-December (after leaf fall) and through January but only on frost-free days, as cell damage can occur if freezing or below. It is advisable to collect some subjects such as *Acer* and *Betula* early (December) to prevent heavy sap bleeding from mother trees.

Scion wood should be collected swiftly, kept cold and be well watered for optimum results

Successful scion and rootstock graft union

Winter scion wood can be stored in polythene bags in a cold store for up to 8–10 weeks. Alternatively, it can be stored in co-extruded bags, black on the inside, white on the outside on a concrete floor in a cold shed or barn for several weeks. For conifers and other evergreen subjects, it is best to collect and graft straightaway.

Rootstocks and scion compatibility

Compatibility between scion and rootstock can be a complex subject if one examines the wider options available. In some cases it is possible to use different species of rootstock and scion and obtain good results. One example would be in the *Rosa*ceae family where *Amelanchier*, *Crataegus*, *Malus*, *Pyrus* and *Sorbus* are often interchangeable. However, for simplicity, it is best to be cautious and use tried and tested combinations. Table 9 (overleaf) provides guidance on the most commonly used combinations.

Symptoms of incompatibility

A range of symptoms can be associated with incompatible graft combinations including:

- Failure to form a successful graft union in the case of a high percentage of the grafted crop
- Differences in growth rate between the rootstock and the scion
- Overgrowths around the graft union
- Breaking of the graft at the union
- Premature leaf abscission towards the end of the growing season
- Decline in vigour and extensive shoot death in the grafted crop
- Premature death of plants after a year to two following grafting

Table 9. Commonly used rootstock and scion combinations for grafting

Rootstock	Scion examples
Abies alba	*Abies koreana* 'Silberlocke', *Abies lasiocarpa* 'Compacta'
Acer campestre	*Acer campestre* 'Carnival', *Acer campestre* 'William Caldwell'
Acer negundo	*Acer negundo* 'Elegans', *Acer negundo* 'Flamingo'
Acer palmatum	*Acer palmatum* 'Garnet', *Acer palmatum* 'Osakazuki', *Acer japonicum* 'Aconitifolium', *Acer shirasawanum* 'Aureum'
Acer platanoides	*Acer platanoides* 'Crimson King', *Acer platanoides* 'Drummondii'
Acer pseudoplatanus	*Acer pseudoplatanus* 'Simon-Louis Freres', *Acer pseudoplatanus* 'Brilliantissimum'
Amelanchier lamarckii	*Amelanchier* 'La Paloma', *Amelanchier* 'R.J. Hilton'
Betula pendula	*Betula utilis* 'Grayswood Ghost', *Betula nigra* 'Heritage', *Betula pendula* 'Tristis', *Betula albosinensis* 'Red Panda'
Carpinus betulus	*Carpinus betulus* 'Fastigiata', *Carpinus betulus* 'Frans Fontaine'
Catalpa bignonioides	*Catalpa bignonioides* 'Aurea', *Catalpa x erubescens* 'Purpurea'
Cedrus deodara	*Cedrus atlantica* 'Glauca Pendula', *Cedrus deodara* 'Aurea'
Cercidiphyllum japonicum	*Cercidiphyllum japonicum* 'Pendulum'
Cercis canadensis	*Cercis canadensis* 'Forest Pansy', *Cercis chinensis* 'Avondale'
Cornus kousa	*Cornus kousa* 'Wisley Queen', *Cornus* 'Eddies White Wonder'
Corylus avellana	*Corylus avellana* 'Contorta', *Corylus avellana* 'Red Filbert'
Corylus colurna	*Corylus colurna* 'Te Terra Red', *Corylus avellana* 'Contorta'
Cotoneaster bullatus	*Cotoneaster* 'Cornubia', *Cotoneaster* 'Hybridus Pendulus'
Crataegus monogyna	*Crataegus laevigata* 'Pauls Scarlet', *Crataegus persimilis* 'Prunifolia Splendens'
Fagus sylvatica	*Fagus sylvatica* 'Riversii', *Fagus sylvatica* 'Dawyck'
Fraxinus excelsior	*Fraxinus angustfolia* 'Raywood', *Fraxinus excelsior* 'Jaspidea'
Ginkgo biloba	*Ginkgo biloba* 'Autumn Gold', *Ginkgo biloba* 'Princeton Sentry'
Gleditsia triacanthos	*Gleditsia triacanthos* 'Sunburst', *Gleditsia triacanthos* 'Ruby Lace'
Hamamelis virginiana	*Hamamelis mollis* 'Wisley Supreme', *Hamamelis x intermedia* 'Barmstedt Gold'
Juglans regia	*Juglans regia* 'Broadview', *Juglans regia* 'Franquette
Laburnum anagyroides	*Cytisus battandieri* 'Yellow Tail', *Laburnum x watereri* 'Vossii'
Ligustrum ovalifolium	*Syringa vulgaris* 'Esther Staley', *Syringa vulgaris* 'Sensation'
Liquidambar styraciflua	*Liquidambar styraciflua* 'Worplesdon', *Liquidambar styraciflua* 'Slender Silhouette'
Liriodendron tulipifera	*Liriodendron tulipifera* 'Fastigiatum'
Magnolia kobus	*Magnolia sprengeri* 'Claret Cup', *Magnolia* 'Apollo'
Malus 'Bittenfelder'	*Malus tschonoskii*, *Malus yunnanensis* 'Veitchii'
Malus M9	Eating apples
Malus M25	*Malus tschonoskii*, *Malus yunnanensis* 'Veitchii'
Malus MM106	*Malus floribunda*, *Malus* 'Rudolph' and eating apples

Table 9. Commonly used rootstock and scion combinations for grafting (continued)

Rootstock	Scion examples
Nyssa sylvatica	*Nyssa sylvatica* 'Wisley Bonfire'
Picea sitchensis	*Picea pungens* 'Hoopsii', *Picea omorika* 'Nana'
Pinus contorta	*Pinus sylvestris* 'Chantry Blue', *Pinus mugo* 'Winter Gold'
Pinus strobus	*Pinus parviflora* 'Glauca', *Pinus strobus* 'Nana'
Prunus cerasifera	*Prunus x blireana*, *Prunus cerasifera* 'Nigra'
Prunus 'Colt'	*Prunus* 'Shirofugen', *Prunus* 'Kojo-no-mai'
Prunus 'Gisela 5'	Eating cherries
Prunus avium	*Prunus* 'Shirofugen', *Prunus* 'Kojo-no-mai'
Pyrus communis	*Pyrus salicifolia* 'Pendula', *Pyrus calleryana* 'Chanticleer'
Quercus cerris	*Quercus castaneifolia* 'Green Spire'
Quercus robur	*Quercus robur* 'Koster', *Quercus frainetto* 'Hungarian Crown'
Quince A	*Pyrus* 'Conference', *Pyrus* 'Doyenne du Comice'
Rhododendron 'Cunningham's White'	Hardy hybrids, *Yakushimanum* hybrids
Rhododendron 'Inkarhro'	Hardy hybrids, *Yakushimanum* hybrids
Robinia pseudoacacia	*Robinia pseudoacacia* 'Frisia', *Robinia hispida*
Saint Julien A	Plums, gages, damsons, apricots, nectarines and peaches
Sorbus aucuparia	*Sorbus* 'Pearly King', *Sorbus* 'Autumn Spire'
Sorbus intermedia	*Sorbus aria* 'Lutescens', *Amelanchier* 'La Paloma'
Tilia cordata	*Tilia cordata* 'Greenspire', *Tilia cordata* 'Winter Orange'
Tilia platyphyllos	*Tilia americana* 'Redmond', *Tilia petiolaris* 'Brabant'
Viburnum opulus	*Viburnum x burkwoodii* 'Mohawk', *Viburnum carlesii* 'Aurora'
Wisteria species	*Wisteria sinensis* 'Prolific', *Wisteria floribunda* 'Lawrence'

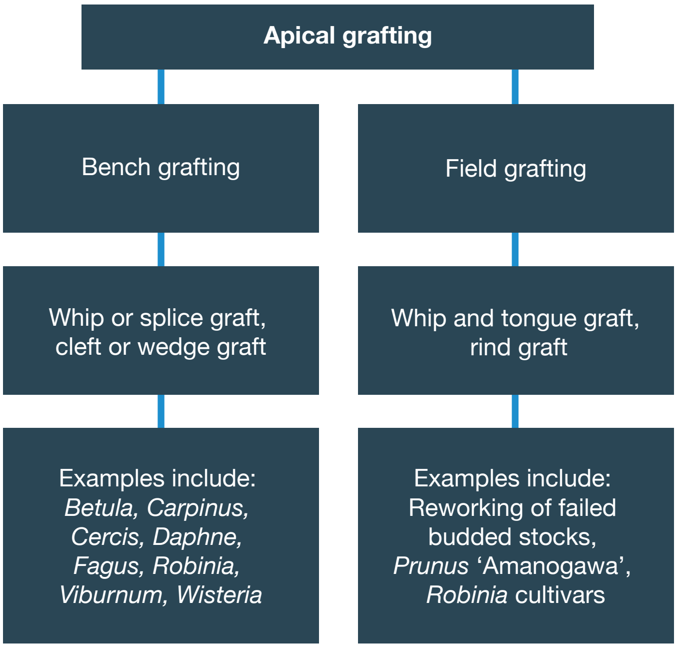
Types of graft

The common methods of grafting and budding are described below. There are two principle grafting techniques.

- Apical graft where the scion and rootstock are joined at their ends
- Side graft where the scion is inserted in the side of the rootstock

The length of the individual scion is a matter of grafters' preference. Having two to three buds exposed after the graft has been tied and sealed is normal. This allows for back-up shoots in case of damage and the graft itself contributes its own stored reserves to the callusing process. If the subject is relatively easy and there is a shortage of scion material, the grafter can elect to 'graft off the stick', that is without preparing individual scions. In this case, a short graft can be used. Figure 7 summarises the most commonly used apical and side graft methods.

A crop of recently side-grafted *Quercus* showing rootstock and scion



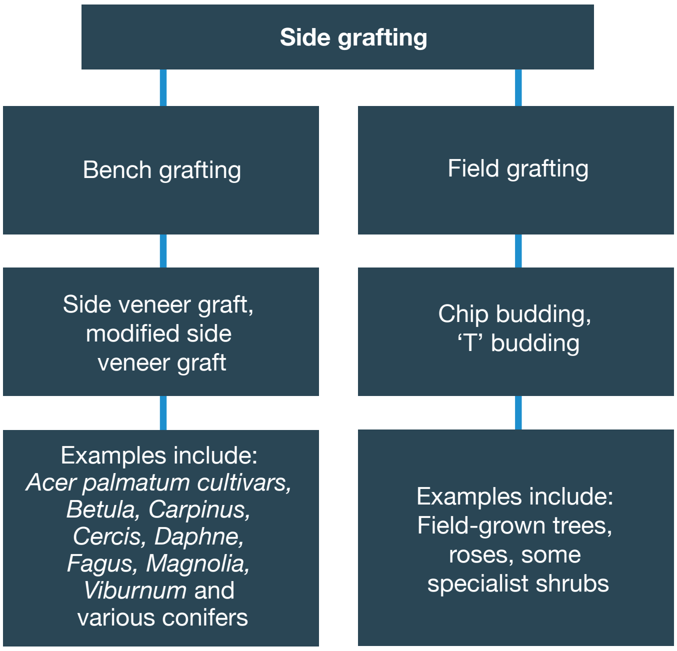


Figure 7. Summary of grafting techniques

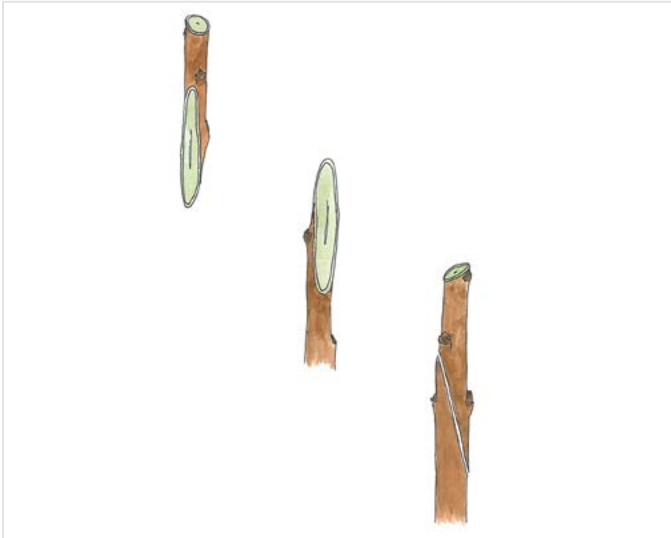
Source: Courtesy of Lee Woodcock, Palmstead Nurseries Ltd

Bench grafting

The winter months of December to March offer a good opportunity for bench grafting bare-root or container-grown rootstocks, while dormant or in mid to late summer (June to August) on container-grown rootstocks. The term bench grafting is literal, as the operation can be undertaken at a comfortable working height.

Whip or splice graft

This is the most simple of grafts, with one slanted upper cut on the rootstock with an equal matched cut on the scion for precise cambium contact. It is ideal where rootstock and scion are of similar gauge and forms a neat clean union. It is very suitable where the grafter is also tying the graft as the whole operation is done in the same movement. This technique is suitable for evergreen subjects such as *Rhododendron*.



Requisite cuts made to the scion (top) and rootstock (middle), with the two cuts joined together to form the graft (bottom)

Whip or splice grafting is ideal where rootstock and scion are of similar thickness, enabling a neat, clean union to be formed

Cleft or wedge graft

This is one of the more versatile methods, where the scion is usually much smaller than the rootstock and where root grafting is also possible such as with *Wisteria* and *Gypsophila*. It is also widely used in laboratories with soft growth on subjects such as potatoes and tomatoes. The scion is prepared as a wedge with equal cuts on both sides and the rootstock is split down the middle. The scion is then wedged in to line up with at least one side of the cambium of stock and scion.

Stages in a cleft graft where the scion material is much smaller than the rootstock

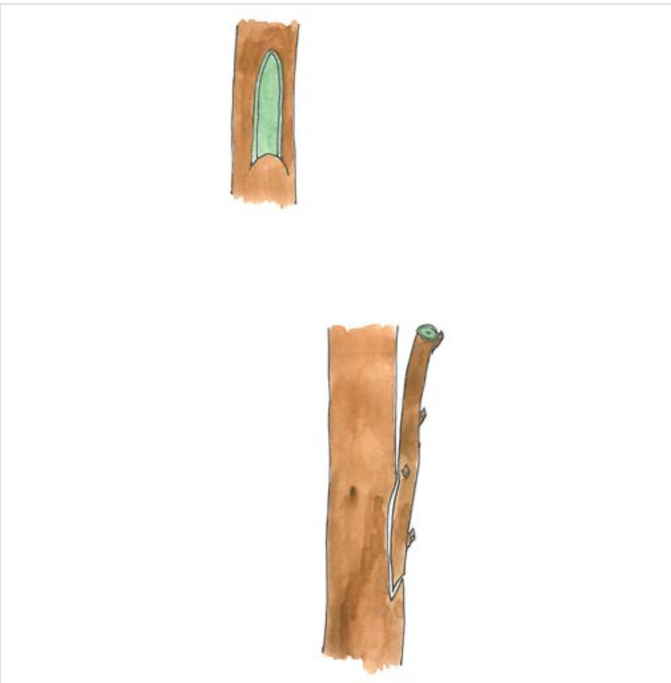
With the side veneer graft, a downward cut is made on the rootstock and a cut of similar length made on the scion such that the cambial layers match up

Side veneer graft

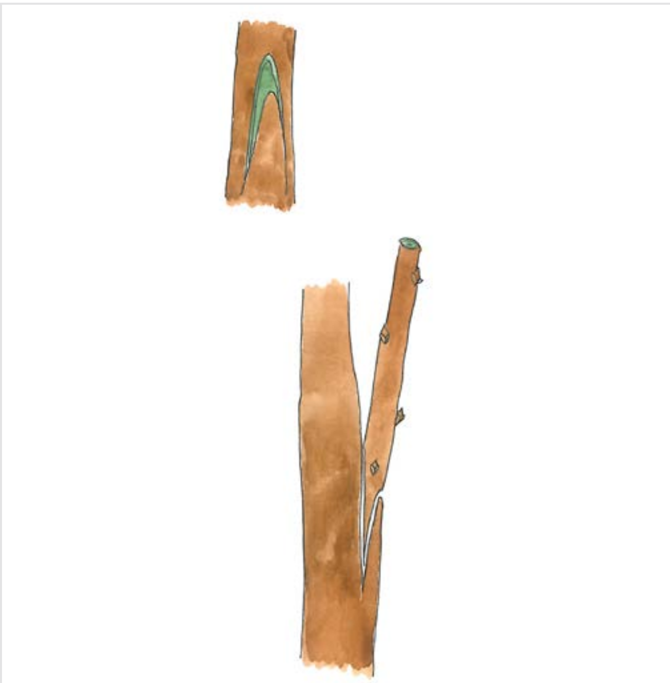
This is the most commonly used method for summer grafting and part or all of the rootstock is retained above the scion after grafting. A downward cut is made on the side of the rootstock to remove a slice of rind, retaining a tongue into which the end of the scion is wedged when tipped off on the opposite side to the main cut. The width of this cut can be estimated to match that of the scion. The side veneer graft is also used for winter grafting.

Modified side veneer graft

This method is very similar to the side veneer but the tongue remaining on the rootstock is extended up over the graft as an additional flap before tying in. The cambium layer is also exposed on the outer side of the graft. This intricate graft is generally only used on particularly difficult subjects, where the extra cambium contact ensures a good 'take'.



A downward cut is made on the rootstock and the tongue is retained at the base of the cut, into which the scion is wedged when tipped off on the opposite side to the main cut



Similar to the side veneer but the remaining tongue on the rootstock is extended over the graft

Rootstock tongue of modified side veneer graft ready to receive scion

Completed modified side veneer graft being tied in

Field grafting

The two grafting methods described here are spring methods using dormant graftwood that has generally been cold stored. The whip and tongue method is not reliant on rising sap, which means it can be undertaken from early March onwards but the rind graft is only successful when the bark is easily separated at the cambium layer. This may be as late as early to mid-April.

Whip and tongue graft

The graft is cut as for a whip graft and a tongue is cut back in on the cut surface, replicating the same on the cut down rootstock, so that the two tongues wedge together. It is important that the cut surface of both rootstock and scion are matched. Generally, with field grafting, the rootstock is larger than the scion but, even so, a precise match can be made if the rootstock is only cut lightly to expose a narrow cambium.

The whip and tongue grafting process with cuts to the scion and rootstock, and their joining together to form the graft

Completed whip and tongue graft secured with biodegradable rubber tie and dipped in wax

Rind graft

The knife blade edge held at 90° is used to make a vertical cut along the length of the rootstock. The graft itself is prepared as for a whip graft, with the end of the scion stubbed so that it can be pushed under the bark of the rootstock, into the cambium layer. The bark will lift and separate but retain enough pressure to hold the graft in place. Tying of the graft is the same as for a whip and tongue graft. This method is often used for top-work grafting in orchards to change varieties.

A downward cut is made on the rootstock with the resulting flap being retained to extend over the inserted scion and completed graft prior to tying in

Field budding

The two budding methods described here rely on the rootstock being active in growth at the same time that the bud wood is mature; these two conditions are key to a successful union of rootstock and bud. Depending on the subject, this could be as early as late June for roses ('T' budding) and as late as mid-September for some fruit trees and ornamentals (chip budding).

Easy plant subjects are tolerant of a wide window of opportunity while the more difficult subjects require more attention to precise timing.

The rootstock is prepared in advance by trimming a clean stem above the ground. Height of budding varies, with roses it is at soil level, in the case of other ornamentals it is at a visually aesthetic height, approximately 10 cm above ground. Fruit trees are usually budded at around 15 cm above ground to avoid the scion rooting at the time of final planting.

Bud wood should be kept moist and in the shade at all times while budding takes place. Material can be kept under a moist cloth or sacking or held in a bucket with the butt-ends in a few centimetres of water.

Whether degradable materials such as rubber or non-degradable polythene tapes are used, the important time for natural or predetermined release is 4–6 weeks. During higher than average ambient temperatures, in combination with good rootstock growing conditions, the callusing will be quicker.

'T' budding

It is only possible to undertake 'T' budding if the plant sap is rising so that the bark lifts easily away from the rootstock. Irrigation is a useful facility to help prepare the rootstock condition to coincide with bud wood maturity.

A short cut around 4 cm long is made along the length of rootstock stem, just deep enough to penetrate the bark and at the top of this another cut is made around 12 mm in length at right angles to the first, in effect forming the 'T' from which the technique takes its name. The bark on either side of the longer cut is then lifted back to receive the bud.

The 'T' budding process, with the bud within the 'shield', the 'T' cut on the rootstock, inserted bud and completed bud with trimmed shield

A bud is then selected and cut from the bud wood, starting around 1–2 cm below the bud. On removal, the wood at the back of the bud is usually left intact and the bud 'shield' inserted into the top of the 'T' cut, pushing down gently to secure it under the bark. Any surplus 'shield' protruding from the cut should then be trimmed off with a sharp knife.

The buds are then tied in firmly but not too tightly, working from the bottom to the top of the wound. The scion bud is left exposed or covered by the tie depending on its vulnerability to damage from pressure during the callusing period. Where bud patches are used, as in the case of roses, these are stretched over the face of the 'T'cut and bud, and held to the stem by staples.

The bud patch gradually degrades as callus develops and the union is formed.

Budded rootstocks are headed back to just above the scion bud the following winter, usually in February or early March.


Making the required cuts in the 'T' budding process


Bud insertion into the rootstock


Bud selection for the budding process


Bud patch


Sufficient 'shield' size on the bud wood to permit easy handling

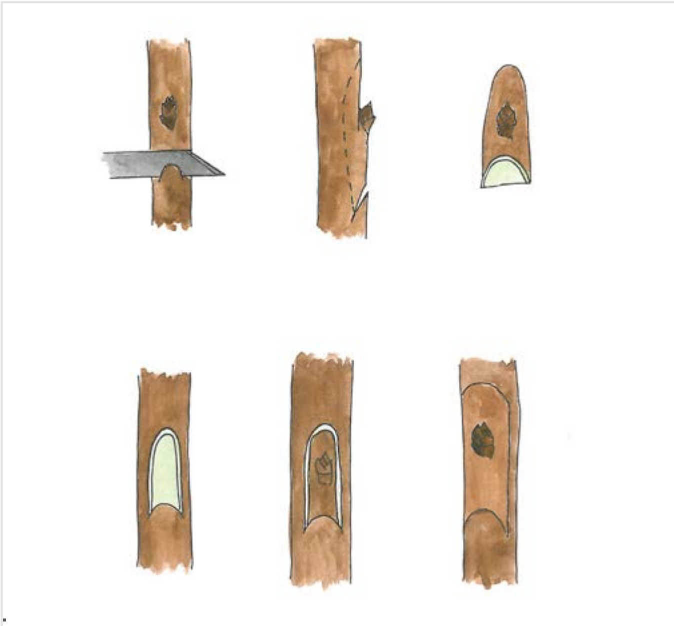

Bud patch degradation

Final union in the budding process

Chip budding

Developed by Dr Brian Howard at NIAB EMR, this form of budding replicates single bud grafting as the cambium layers of rootstock and bud match precisely. It is found to produce a more consistent 'take' for most subjects and will produce a more uniform stand of trees in the maiden year. In practice, it has also proved to be faster for the operator but the tying requires more precision, as the bud is easily shifted offline.

A clean, smooth spot on the stem should be chosen for budding. The first cut into the stem is made at around 20° to a depth of around 3 mm to form the lip on which the scion bud sits. A second cut is made at around 4 cm above this cut and an inverted U-shaped cut is then made back down the stem to the first cut.



The chip budding process, showing preparation of the bud (top) and rootstock (bottom) together with the bud and rootstock together on completion

Required cuts in the rootstock to receive the bud

On the bud wood, the scion bud is removed by making similar cuts and then lifting it between thumb and knife blade. It is then transferred to the rootstock where the cut lip should firmly hold the bud. Matching up the cambium layers of both scion bud and rootstock is again the prime aim.

Bud in position on the rootstock

The same methods and principles apply to tying chip buds as for 'T' budding. As chip buds are more exposed than a 'T' bud, tying accurately to secure the bud correctly is more critical.

Tying in the chip bud needs to be an accurate procedure

Chip budding is now the accepted technique for ornamental deciduous subjects as well as fruit trees. It can also be done using container-grown rootstocks.

Chip bud on a container-grown rootstock

Propagation facilities

Winter grafting

Bench grafting procedures are carried out during the winter months with dormant material. It is critical that the scion material of deciduous subjects is fully dormant.

With bare-root grafting, the completed grafts can be plunged in a moist medium and potted up when the buds are bursting on the scion or dormant from cold store.

When grafting onto container-grown rootstocks, these will need to be brought under protection, if they have been grown outside, and well before grafting takes place October is not too early. This is because the medium in the pot needs to be dried out to a just moist condition prior to grafting.

Deciduous material can be dipped in molten wax and stood on open benches or beds on the floor of the protected structure.

Conifers and evergreens will need to be placed in a polythene tent where high humidity can be maintained (as can deciduous material if not waxed).

Base heating, whether in beds on the floor or raised benching, is most important, as activity in the rootstock needs to precede that of the scion. Therefore, air temperatures need to be cool. Base temperatures of 18–20°C are high enough. Other than in severe weather, base heating usually ensures frost-free conditions, even in polythene tunnels.

Air heating facilities should be considered to augment the base heating during very cold periods, especially if these occur in February and March when grafts could be making growth. The provision of heat will speed up the uniting of rootstock and scion so protected facilities for growing the grafts on will be required.

When using facilities with no form of heating, it is important for the uniting of rootstock and scion to be a slow process. Bud burst and commencement of growth should only be two to three weeks earlier than the plants natural bud burst outdoors.

It is, therefore, important on sunny days to vent the glasshouse or polythene tunnel to prevent air temperatures getting much higher than the outside temperature.

There is always a risk of prolonged freezing periods causing damage to the grafts and it is here that portable heaters would be required.

Summer grafting

Some subjects such as *Acer palmatum*, *Hamamelis* and *Magnolia* are suited to this system and are heavily reliant on the side veneer method.

By necessity, container-grown rootstocks are used, which do not need to be brought inside prior to grafting. They should be kept moist at all times and not allowed to dry out.

Leaves are retained on the scion or can be reduced in size if large. It is important to use well-ripened scion wood. No time should be lost in getting completed grafts to the propagation facility.

Normally, low polythene tents are used but fogging units are an alternative. Weaned and established grafts can be grown in outdoor frames, cold glasshouses or polythene tunnels for the rest of the summer period.

Use of cold stores

Cold stores can be used to extend the grafting or budding season by keeping scion wood, bud wood and rootstocks dormant, if this is required. They are also useful for short term storage of summer scion wood and bud wood, helping to remove 'field heat' and keep material fresh. Direct cold airflow systems generally dehumidify the air so plant material will either need to be sealed in plastic or held on shelves and the floor of the store watered regularly. A jacketed cold store with indirect cooling is preferable.

Hot-pipe callusing

This technique is particularly useful for subjects prone to failure at the critical point where callus formation is not adequate to support the early growth stage of the scion. This difficult transitional period is assisted by pre-callusing the graft union while the rootstock and scion remain dormant, thereby reducing losses at the weaning stage. It also allows a wider use of bare-root rootstocks in place of container-grown ones, reducing costs considerably. It is also particularly suitable for all apical grafting and allows this simpler graft to replace side veneer in some situations.

Subjects particularly suitable for this method are shown in Table 10. Most species within these genera apply. In principle, any grafting subject can be 'hot-piped' if the temperature and duration is known, however, the extra cost of the operation is not justified for many of the easier to propagate subjects.

Hot-pipe construction

Several heat sources are equally as effective, including electric soil warming, self regulating cables and hot water systems. The important design feature is to be able to focus heat over the graft union accurately without any fluctuation of more than 1–2°C either way and to keep the outer perimeters of scion and rootstock cool.

Table 10. Optimum times and temperatures for a range of subjects when hot-pipe callusing

Subject	Max time (days)	Temperaure (°C)	Callus formation
Aesculus	18	22	Average
Amelanchier	18	20	High
Betula	18	22	Average
Carpinus	16	22	High
Castanea	18	22	High
Corylus	14	20	High
Fagus	18	20	Average
Gleditsia	18	20	Average
Ginkgo	18	22	Average
Liriodendron	16	24	High
Morus	18	20	High
Juglans	18	18	Low
Quercus	16	22	Average

Bare-root grafts ready for hot-pipe callusing

Bare-root grafts being laid out for hot-pipe callusing on an electric self-regulating pallet system

Grafts in position for hot-pipe callusing; the roots are covered with peat to conserve moisture and the graft union positioned to receive heat

Heat must be well controlled and focused around the graft unions, enabling the rest of the scion and rootstock to remain cool

The key principles of hot-pipe callusing are:

- Roots must be kept moist at all times
- It is important not to exceed the recommended temperatures or times
- It is advisable to maintain a slight air gap between heat source and graft to avoid hot spots
- Even small amounts of callus are advantageous to graft survival
- Some sucker development around the union is acceptable
- Cold storage of callused grafts after removal from the bed is acceptable
- Plant material should harden off over 2–3 days after the times stated in Table 10

Aftercare

This is as important as the grafting and budding processes to avoid unnecessary plant losses.

Bench grafted material

The most important factor with container-grown grafts is regulating moisture content at the 'just moist' level; if allowed to get wet, either by over watering or from condensation drips, failure will occur. If allowed to get too dry, losses can also occur. Bare-root grafts can also be lost when potted up if watered too much before they make new root. Watering should only be increased when the grafts start making reasonable growth.

Timely removal of suckers is important so they don't compete with scion growth, although some sucker growth may help to avoid overwintering problems. Early caning and tying in of new growth is crucial and the need for prompt pest and particularly disease control is essential.

Field grafted material

Non-degradable ties such as polythene grafting tape should be removed once a well-established graft union has formed and before any constriction takes place due to expansion of the rootstock. This is also necessary to avoid fungal infections that may develop beneath the ties if they remain in place too long.

Shoots should grow away strongly once the union has formed. Any double leading shoots should be cut back by about half, leaving the strongest and straightest intact to grow on. Any lateral shoots should also be pruned back and rootstock suckers rubbed out while they are still soft. Pests and diseases should be controlled promptly and the area kept free of weeds.

During the maiden year, any further rootstock suckers should be removed promptly and those subjects requiring support caned and tied, placing the cane at the back of the graft union. A top-dressing of fertiliser should be applied in the spring or summer if required, in accordance with soil analyses. Good levels of weed control should be maintained to minimise competition.

Field budded material

Non-degradable ties should be removed promptly once a well-established bud union has formed. Pests, diseases and weeds should also be kept under close control.

The rootstock tops should be removed ('headed back') to just above the scion bud during the late winter period to enable maiden growth to develop unhindered.

Good weed control should be maintained throughout the maiden year and a top-dressing of fertiliser applied during the spring or summer period in accordance with soil analyses.

Subjects requiring support should be caned and tied promptly, placing the cane at the back of the bud union. With chip budded material, bud guides can also be used to direct and protect the leading shoot as it emerges from the bud, helping to avoid the characteristic 'dog leg' that may otherwise develop at this stage.

Division

Many herbaceous perennials, alpine plants and ornamental grasses can be propagated quickly, reliably and economically by the division or splitting of crowns. While fairly straightforward to do, division does require significant quantities of stock. It is also labour intensive work and its use has declined in favour of other methods, notably seed or cutting raised plug plants and, to a lesser degree, the use of micropropagated material.

Herbaceous perennials that can be propagated by division include *Aster*, *Astilbe*, *Bergenia*, *Doronicum*, *Epimedium*, *Geranium*, *Hemerocallis*, *Helenium*, *Hosta*, *Iris*, *Rudbeckia* and *Stachys*. Many mat-forming and ground cover alpines can also be increased by smaller mini-divisions, usually in spring when the plants are actively growing, including *Chiastophyllum*, *Gentiana sino-ornata*, *Geranium*, *Lysimachia*, *Polygonum* and *Raoulia*. Various mossy and rosette forming *Saxifrage* species, *Sedum*, *Sempervivum* and Thymus can also be propagated in a similar way, although in effect these are more like rooted cuttings than true divisions, due to the nature of the plants.

Division is also a useful and speedy way of propagating clump forming bamboos and ornamental grasses such *Carex*, *Festuca*, *Miscanthus*, *Phyllostachys*, *Sasa* and *Stipa*.

Although division is done primarily during the quieter autumn and winter months when the crowns are dormant, some crops respond well to summer propagation after flowering, notably *Doronicum*, *Epimedium*, *Hemerocallis* and *Iris*. Divisions of *Iris*, typically, comprise a small portion of rhizome with roots attached and a 'fan' of leaves that are trimmed to about half their size. With *Epimedium*, young rhizomes produced after flowering are cut up into smaller pieces, each with roots attached and either lined out or potted up for growing on.

Dormant crowns are split into as many pieces as possible, using the younger, more productive outer portions rather than the older central core. Each division should have roots and dormant buds attached although some subjects (such as *Hosta*) usually comprise single bud divisions while others (like *Aster* and *Stachys lanata*) are more like rooted cuttings.

Similarly, the thick fleshy rhizomes of *Bergenia* can be cut up into small sections, typically 3–4 cm in size, each with a dormant bud attached. Due to their small size, they are usually inserted horizontally (bud uppermost) into seed or plug trays or small pots and propagated on a heated bench or bed (at 18–21°C), under clear polythene covers initially, until the buds are forced into growth. Once new roots have developed, the young plants are potted and grown on under protection until well established.

During splitting, any dead or decaying foliage is removed. Ornamental grasses with long foliage such as *Carex*, are usually trimmed to reduce the leaves to about half their length to enable easier handling and encourage vigorous, compact growth in spring.

Following division, the young 'splits' are usually potted for growing on the following spring or lined out in the field. Cold storage can be used to hold stock back until planting conditions are suitable or bed space is available for potting.

Layering

Layering involves rooting shoots while they are still attached to the parent plant. There are several ways of doing this. Simple layering involves pegging down shoots produced the previous year, usually at their tips. French layering involves the pegging down of shoots along their entire length, such that new, upright shoots develop along the complete length of stem and serpentine layering is an adaption for species producing long annual shoots.

It is one of the oldest propagation techniques and, until the end of the eighteenth century, was the chief method used. However, its commercial importance declined as the rooting of stem cuttings became better understood, aided by the advent of mist propagation during the 1950s. Its labour intensive nature and attendant difficulties with weed control also contributed to its decline. However, it is a reliable technique for the propagation of HNS subjects that are difficult or very slow to root from cuttings, particularly those required for sale on their own roots. Large saleable plants can be produced quite quickly, such plants are normally rooted in the first year and grown on for sale during the second.

Simple layering

This is usually carried out during March to June when shoots are in active growth. Strong, young shoots produced the previous year are arched over and pegged down around the stock plant so that they root into the

Iris responds well to summer propagation and is one of many herbaceous subjects that can be increased readily by division surrounding soil. While these are rooting during the summer, new shoots emerge that are pegged down the following year, to continue the cycle and provide a succession of shoots.

Normally, rooted layers can be lifted from autumn onwards, lined out or potted for growing on. Most subjects will be well rooted within one growing season, although slower species like *Magnolia* and *Rhododendron* will require leaving down for longer, usually around 18 months.

For all layering techniques, adequate irrigation during dry periods is essential, as is prompt control of weed problems and good nutrition.

HNS subjects suitable for simple layering include: *Celatrus, Chimonanthus* (in July and August), *Cornus controversa, Corylus avellana, Corylus avellana 'Contorta', Corylus maxima 'Purpurea', Corylopsis, Cercidiphyllum japonicum, Hamamelis, Fothergilla* (in August), *Parrotia persica, Stachyurus praecox, Syringa microphylla 'Superba', Syringa vulgaris cultivars, Tilia cordata, Tilia x euchlora, Tilia x europaea, Viburnum plicatum* cultivars, *Viburnum tomentosum* and *Wisteria*. Deciduous *Azalea* can also be layered if soft cuttings prove difficult and while many species and cultivars of *Rhododendron* are now raised from cuttings, simple layering is a useful alternative.

French layering

This technique yields considerably more plants from a single shoot and in turn each stock plant, than simple layering in which each stem produces just the one plant. The annual management programme differs in that the pegging down horizontally (as distinct from arched in the case of simple layering) of shoots for their entire length is usually done during January or February. During the spring, the new shoots formed from buds that have broken along the length of stem, are gently covered with soil when around 5 cm in height, such that only the tips are visible above soil level. In effect, they are 'earthed up' and the process is repeated once or twice more when the shoots have made further growth to ensure the horizontal shoots are covered with around 15 cm of soil. Usually, this work is completed by early summer and the plant material is lifted from autumn onwards.

HNS subjects suitable for French layering include *Acer cappodocicum* 'Rubrum', *Acer saccharinum* 'Laciniatum', *Alnus cordata*, *Alnus incana*, *Carpinus betulus* 'Fastigiata', *Chiminanthus praecox*, *Chiminanthus praecox* '*Lutea*', *Corylus colurna*, *Corylus avellana* 'Aurea', *Corylopsis pauciflora*, *Cotinus coggygria* and cultivars, *Euonymus europaeus* 'Red Cascade', *Hydrangea paniculata*, *Hydrangea quercifolia*, *Styrax japonica*, *Tilia platyphyllos* 'Rubra', *Viburnum bodnantense* and *Viburnum farreri*.

Serpentine layering

This technique is adapted to species producing long annual stems such as *Clematis* and *Wisteria*. The stems are brought down to ground level and buried at intervals along the stem in a snake like fashion, leaving at least one bud on each above ground portion of stem. New shoots grow from the buds and roots from within the buried area, at which point the stems are sectioned and young plants lifted when established to be grown on.

Stooling (mound layering)

This is the simplest form of layering, relying as it does on the principle that if a young stem is placed in darkness it will produce adventitious roots. It is also a relatively efficient method of propagation, enabling the production of a large number of well-rooted plants per unit area. However, it is only suitable for vigorous, usually deciduous subjects able to withstand and replace annually the removal of all shoots during the dormant period by quite severe pruning.

Stool beds remain the principal propagation method for raising apple rootstocks

Once established, shoots produced by the stool bed are earthed-up in spring to blanch them and so induce root initiation. This process is repeated twice more as the shoots grow during the summer. The rooted stems are then pruned away in mid-winter from the parent plant for transplanting and growing on.

Typically, the economic life of a stool bed varies from around 12 to 20 years depending on species and how well it is managed. Usually, they are fully productive within three to four years after planting.

Although largely superseded by advances in the rooting of stem cuttings, stooling is an alternative and reliable, if labour intensive propagation method, for a range of HNS subjects including cultivars of *Acer cappadocicum, Acer saccharinum* and *Acer palmatum*, various 'snakebark' maples, *Berberis* species (notably, *Berberis dictophylla* and *Berberis temolaica*), *Cercis, Chaenomeles, Chimonanthus, Cornus*, *Corylopsis spicata, Cotinus, Halesia, Hoheria, Hydrangea paniculata, Morus, Prunus glandulosa, Prunus tenella* and *Prunus cerasifera* cultivars, *Ulmus*, *Viburnum bodnantense* and *Viburnum farrerii*.

Young shoots are earthed up regularly when in active growth to promote rooting and then pruned away in mid-winter for growing on

Propagation environments and systems

Influence of water, temperature and light

The essential environmental requirements for propagation via cuttings include: a humidity level sufficient to reduce water loss from leaves, an appropriate temperature regime (this will vary with species) and adequate natural light. These can be provided by simple, close-contact propagation film laid directly over cuttings, polythene tent or 'cloche' systems or various mist or fog systems. The latter providing the high humidity supportive environment needed to root very soft material.

Water

When cuttings are removed from the parent plant, their natural water supply to the leaf from the roots ceases, yet water loss by transpiration continues. This results in water stress that can prevent rooting and promote rotting. Many easy rooting HNS subjects avoid serious water stress by closing stomata quickly and continuing to take up water through the cut base. More difficult rooting species are less able to avoid water stress and so require a more supportive environment until adequate new roots have formed. Similar remarks apply to soft cutting material prone to rapid water loss.

To reduce transpiration and water loss to a minimum, the vapour pressure of the water in the atmosphere surrounding the leaves of the cuttings should be maintained to a point that is almost equal to the vapour pressure in the intercellular spaces within the leaf. To do this, a high relative humidity is required, combined with leaf wetting to help prevent leaves becoming warmer than the air around them (the internal water vapour pressure increases rapidly with temperature).

The development of mist propagation during the 1950s was a major advance in improving the rooting of soft, leafy cuttings, relying as it does on the evaporative cooling effect of moisture on a leaf surface. This cooling effect reduces the internal water vapour pressure in the leaf and, in turn, the rate of transpiration. Maintaining a film of moisture over the leaf surface also creates the requisite high relative humidity around the leaf and lowers the air and leaf temperature, each of which also contribute to reducing transpiration rates.

Under well-controlled mist or fog, environmental conditions are usually ideal for rooting leafy cuttings. Transpiration and so water loss from cuttings is reduced to a low level while natural light intensity can be high, so promoting full photosynthetic activity. As the temperature of the cutting is relatively low, the rate of respiration is reduced and so, in turn, the use of valuable food reserves, which are important for root initiation and development.

Mist has enabled soft leafy cuttings to be propagated early in the season at a stage most favourable for rooting. Without mist or fog, such material would be difficult to keep turgid and root. The capability of the two systems to reduce water loss also enables larger cuttings to be used with greater leaf areas. This often leads to improved survival, a greater number of healthy, vigorous roots and a larger liner in a shorter space of time.

Mist and fog systems require careful management to be effective. Shade and some ventilation will be required during hot spells in spring and summer, while the application of water must be well controlled to avoid drying out or, more usually, overly wet conditions prevailing.

Excessive water application also reduces the temperature of the propagation medium, which may in turn reduce rooting. It also leaches and so depletes cuttings of valuable nutrient reserves necessary for optimum rooting. Disease risk (notably from *Botrytis*, *Pythium* or *Phytophthora*) is also greater, underlining the need for efficient control of water application to prevent disease establishment and spread.

Temperature

Most HNS subjects will root well with quite modest air temperatures so long as there is sufficient base heat provided at the point of root initiation (although many species will root equally well cold without such heat).

In terms of day and night-time air temperatures, 15–18°C and 12–15°C, respectively, will suffice for most situations, while base temperatures will vary considerably, from zero (cold) for easy rooting subjects to 21°C for slower more difficult to root species, at least for the initial few weeks following insertion. As a general guide, for cuttings requiring base heat, 18–21°C is usually adequate.

Light

As light is the energy source for photosynthesis, its presence is of major importance in all types of plant growth, including root initiation and growth. With leafy cuttings, light intensity and duration must be sufficient to enable carbohydrates to accumulate in excess of those expended during respiration. In leafless hardwood cuttings, such dependence is drawn from food reserves within the cutting.

Generally, the more light a cutting receives within certain limits, the more likely it is to develop a strong root system, but its ability to benefit from high light depends on how well the propagation environment limits water loss and avoids excessively high temperatures. High temperatures increase respiration and so deplete carbohydrate. It also becomes more difficult to restrict water loss as temperatures increase.

Excessive shading also will limit photosynthesis, so reducing carbohydrates necessary for root formation and development but, as a guide, 20% shade is considered optimal during the spring and summer period.

The absence of light on stem tissue in the region where roots are expected to form is of course conducive to rooting in many HNS species and is exploited for commercial purposes through the process of layering and the etiolation of stem cuttings to enhance rooting, for example, with cultivars of *Syringa*.

In some subjects, the lighting level under which stock plants are grown may influence the rooting and subsequent growth of cuttings they produce. Certain species cease active growth in response to a natural reduction in light intensity and day length. For example, with spring rooted cuttings of deciduous *Azalea* and dwarf *Rhododendron* potted on during late summer or early autumn.

The growth of such plants improves considerably if placed under continuous supplementary lighting under glass in winter compared to plants grown in normal short winter days, which usually remain dormant until the following spring.

Understanding the environmental needs of cuttings

AHDB Horticulture project HNS 9: ***Understanding the environmental needs of leafy cuttings during rooting***, considered the environmental needs of cuttings more closely and sought to assess the variability of propagation environments for leafy summer cuttings on a cross-section of commercial HNS nurseries, using polythene or automated mist or fog systems. From the work, it was clear that:

- Conditions varied greatly in many respects crucial to rooting and survival and that a high proportion of cuttings were experiencing suboptimal conditions during propagation
- There was a worrying lack of awareness among nurserymen of what constitutes a good environment for propagating leafy cuttings, a view supported by the variable conditions observed on the nurseries as part of the study
- There were significant differences in light intensity, relative humidity and leaf wetting between nurseries and, more worryingly, within propagation areas on the same nursery. These were often the result of deficiencies in control equipment, low water pressure, partially blocked nozzles and inadequate closure of the environment
- Nurserymen still relied heavily on experience rather than technology for control of the propagation environment, much of which was needed to counteract mechanical deficiencies. However, this often failed to have the desired effect. For example, manual opening of vents frequently reduced relative humidity more than it did high temperatures, as intended

AHDB Horticulture project HNS 76: ***Examination of techniques to raise humidity in mist houses***, investigated ways in which propagators could achieve the environmental conditions needed for the cuttings of stress sensitive species to root successfully, for example, softwood cuttings of *Cornus, Cotinus and Garrya.*

Such cuttings require a combination of generous leaf wetting and an atmosphere that is almost saturated with water vapour (close to 100% relative humidity).

This can be achieved with a good fog system, although mist is still preferred by many propagators because of its reliability and suitability for rooting a wide range of HNS subjects successfully. Early problems with fog included a tendency for over wetting and difficulties with temperature control, particularly in non-vented systems.

Polythene enclosed mist systems (so called closed mist systems) can achieve comparable results to fog but suffer from excessively high temperatures unless well shaded and carefully managed. Cuttings are also less visible and so more difficult to manage. However, they offer a cheaper alternative to fog and a more constant level of humidity compared to the more cyclic patterns of leaf wetting associated with open mist. They are, therefore, less inclined to become overly wet.

Closed mist systems are also flexible, in that they can be readily adapted for autumn and winter propagation by reducing or simply switching off the mist for subjects preferring a drier regime, for example, in the case of many conifers and evergreen species.

In HNS 76, rooting trials with leafy cuttings of a range of HNS species in a large-scale closed mist system were compared with a highly successful ventilated fog system and a conventional open mist system, following initial studies examining the factors determining the temperature and humidity achieved in a well-sealed polythene enclosure.

A range of HNS subjects were included in the study including: *Acer platanoides* 'Crimson King', *Acer platanoides* 'Drummondii', *Cornus alba* 'Elegantissima', *Corylus maxima* 'Purpurea', *Cotinus coggygria* 'Royal Purple', *Garrya elliptica* 'James Roof' and *Magnolia soulangeana.*

Apical cuttings were predominantly used, treated with an IBA 'quick dip' and struck during July and early August. For the main subjects, assessments for rooting, basal decay and root-ball volume were made at 28 and 55-day intervals.

The conclusions from the project are presented below:

- Closed mist systems can be scaled up sufficiently to make them attractive to propagators, increasing them to a large, walk-in enclosure enabling easier, regular inspections of cuttings, with several mist lines rather than one
- The humidity level achievable in a large-scale closed mist system was comparable to that of a good fog system
- The high humidity in a closed mist environment became localised to the misted area, if only part of the enclosure was misted. If the mist interval was too long then humidity dropped between bursts
- For the most sensitive HNS subjects, fog was more supportive than closed mist; *Garrya elliptica* 'James Roof', for example, rooted 100% in four weeks in fog compared to 67% after eight weeks in closed mist

- The addition of small quantities of fine droplet fog, such as can be produced ultrasonically, to raise the humidity of incoming air in ventilated mist environments enabled additional support, such that the advantages of fog (humidification of incoming air) and mist (uniform leaf wetting) were combined for best effect. As ultrasonic foggers have a low output, mist will provide the main support during stressful conditions
- Initial tests indicated that such a system enabled limited ventilation of closed mist without the relative humidity falling substantially below 100%
- Under bed insulation (to reduce energy loss) tended to increase temperature lift in closed mist systems by reducing heat loss into the ground. The degree to which this occurred depended on the heat storage capacity of the material above the insulation layer
- Floors or benches with capillary matting offered minimal thermal buffering, leading to larger temperature variations
- Heat loss by radiation is unlikely to account for much of the heat loss from closed mist systems, as both water and UV stabilised polythene absorb radiation quite strongly in the infrared waveband

Recommendations from the project

To create a more supportive environment in large-scale closed mist systems:

- Ensure the enclosure is robust and well sealed as even a small opening can dramatically reduce humidity
- Ensure the entire floor area, including access paths, is kept wet by periodic damping down
- Be aware that heavy condensation on the polythene provides no guarantee that humidity is high around the cuttings
- Use external reflective shading to minimise heat load; this is essential and more effective if supported away from the polythene of the enclosure
- Use floor level beds rather than benches or beds with under bed insulation, as these are less likely to lead to higher daytime temperatures
- Use at least 5 cm of sand beneath the propagation trays to help ensure that the rooting medium is well drained, even during frequent misting, and to limit maximum temperatures, even if under bed insulation is used

This work showed that fog provided a slightly more favourable environment than enclosed mist (particularly with *Garrya* cuttings) despite there being no detectable difference in humidity and cuttings appearing well wetted throughout, in both systems. The more supportive environment of fog is thought to be due to the more constant humidity it provides around the cuttings.

Water loss from leaves depends on the conditions immediately outside their stomata, which in most HNS species are concentrated on the underside of the leaves. As the leaves absorb radiation, they tend to warm up and this warmth is then transferred to the air passing close to them. Thus, even if the air is saturated, the relative humidity drops and the vapour pressure deficit increases next to the leaves. However, if there are droplets of liquid water suspended in the air, as there are with fog, then those droplets will tend to evaporate and so maintain a relative humidity close to 100%.

Although the wider conclusion from this work was that considerable improvements over conventional ‘open’ mist are possible without the need to deploy fog, a modest input of (ultrasonic) fog to complement mist may yield greater improvements, at least with some subjects propagated by leafy cuttings.

Not all HNS subjects require or even benefit from a more supportive environment; it is mainly those considered difficult to root that are likely to respond significantly.

Light levels and shading

Light levels are the single most important factor regulating the rate of water loss from cuttings. While light is essential for photosynthesis and developing adequate carbohydrate reserves needed for root growth, too much light results in drying out and poor rooting.

There is also some evidence to suggest that high light can have an inhibitory effect on rooting. For example, at the former Glasshouse Crop Research Institute (GCRI) in Sussex, when *Viburnum x bodnantense* ‘Dawn’ was propagated under mist using varying degrees of shading, best rooting occurred at the lowest light level with progressively poorer rooting as the light increased. Subsequent leaf tissue measurements showed no appreciable differences in turgor, suggesting that light alone was in some way inhibiting rooting, a conclusion also drawn from other research work.

During propagation, a balance needs to be struck between keeping cuttings turgid and allowing sufficient photosynthesis to produce adequate carbohydrates for root formation and growth. During the spring and summer period, this is usually achieved by mist or fog but work by Dr Keith Loach at GCRI showed that, by using shading to control light levels, it is possible to achieve good rooting using cheaper systems, namely contact polythene (although this work can also be extrapolated to polythene tents).

This work established appropriate light levels for successful HNS propagation under polythene; rooting declines rapidly when daily radiation falls below 1.5 megajoules (MJ)/m^2 and optimally should be about twice this value, 3 MJ/m^2 (typically, the daily radiation in the UK ranges from around 2 MJ/m^2 in mid-winter to 20 MJ/m^2 in midsummer).

Shading regimes need to take account of the naturally wide variations in daylight that occur in different months of the year, time of day and different weather conditions.

Automatic shade screens that can be drawn over propagation beds at a preset light level provide the requisite flexibility to respond to variations and adjust the shade levels accordingly but, in situations where shading regimes are run manually, a subjective decision has to be reached whether it is a 'dull' or 'bright' day and a shade level selected accordingly. This, of course, may change during the course of the day.

During the GCRI work, a shading schedule (Table 11 below) was devised to guide growers on appropriate shade levels in propagation areas for different months of the year and weather conditions.

While very much an approximation, it provides a useful point of reference, particularly when propagating under polythene, where temperatures can build up rapidly beneath the cover. Cuttings under mist will tolerate a wider range of light levels, but the information provided can still be used for guidance.

Good rooting of many HNS subjects can be achieved under polythene systems using shading to help control light levels

Table 11. Shading scheme for propagation of woody ornamentals under polythene

Month	Number of layers* of 40% shade cloth** required					
	Sussex Day type***		Southport Day type***		Stirling Day type***	
	Bright	Dull	Bright	Dull	Bright	Dull
January	0	0	0	0	0	0
February	1	0	0	0	0	0
March	2	0	2	0	1	0
April	3	1	3	1	2	0
May	3	1	3	1	3	1
June	3	1	3	1	3	1
July	3	1	3	1	3	1
August	3	1	3	1	3	0
September	2	0	2	0	2	0
October	1	0	1	0	1	0
November	0	0	0	0	0	0
December	0	0	0	0	0	0

* If glasshouse is whitewashed (April to August) use one less layer than in the table.

** 1, 2 and 3 layers of 40% shade cloth cut out (theoretically) 40, 64 and 78%, respectively, of incident light. Checks showed reasonable agreement with these figures.

*** A subjective judgement of the day type is made each morning and the appropriate shade cloth is used, supported above polythene covering the cuttings.

Note: Shade levels are calculated to give an average daily radiation of around 3 MJ/m^2.

This scheme did not allow for time of day variations. At GCRI, two different levels of shade were used through the day; a light shade for early morning (8.00–10.00am) and evening (3.00–6.00pm) and a heavier shade for the middle part of the day (10.00am–3.00pm), depending on the month.

The results of summer propagations (usually, the most challenging period for rooting cuttings under polythene) are detailed in Table 12. Clear, light gauge polythene was laid directly over the top of the cuttings and the shade cloth supported 50 cm above it. A light level averaging around 3 MJ/m^2 was achieved using appropriate shade levels based on a subjective judgement of dull and bright days. With three subjects (*Cornus, Corylus* and *Philadelphus*), better results were achieved under polythene than under mist. Subsequent work also confirmed that properly shaded polythene gives equally good and often better results than conventional mist with potential for substantial energy savings.

Once rooted, a cutting will require higher light levels for optimal growth and should, therefore, be removed (gradually) from the shaded regime.

Table 12. Comparison of percentage rooting of summer cuttings under mist and shaded polythene

Month and plant species	Percentage rooting	
June/July	Mist	Polythene
Forsythia intermedia 'Lynwood'	96	100
Philadelphus 'Burfordensis'	59	95
Potentilla fruticosa 'Red Ace'	100	100
Weigela florida 'Variegata'	100	100
July/August	Mist	Polythene
Callicarpa bodinieri	97	95
Cornus alba 'Sibirica'	47	73
Corylus maxima 'Purpurea'	10	25
Hydrangea 'Altona'	95	98

Interaction of light and moisture

Light and moisture are the two environmental factors requiring most attention when seeking to optimise the rooting of leafy summer cuttings; they interact strongly because light, while essential for photosynthesis, stimulates water loss and so increases the risk that cuttings become water stressed.

AHDB Horticulture project HNS 55: ***Strategies for liner production designed to achieve high-quality container plants***, highlighted big differences in environmental response between species, especially to water. *Cryptomeria japonica* 'Elegans Compacta', for example, only rooted when there was little or no wetting, while *Garrya elliptica* 'James Roof' required very heavy wetting to root well and *Cotinus coggygria* 'Royal Purple' rooted best when heavily wetted with high light (but tolerated less moisture at lower light levels).

In this work, most subjects failed to root if the light level was very low. On the next page Table 13 summarises the environmental requirements identified during the work.

Several other conclusions were also drawn from this work:

- Most cuttings fail if the light level is less than 2,150 lux (equivalent to what cuttings would receive on average during cloudy weather in summer)
- Most HNS subjects show no further increase in rooting percentage in light levels above 3,250 lux
- Some subjects have higher light requirements (up to 8,100 lux); these usually have a small leaf area relative to stem thickness, such as *Berberis x stenophylla*
- As light levels increase, more moisture is required to avoid a reduction in rooting due to water stress
- At a given light level, subjects vary greatly in their moisture requirement. The larger the leaf area per cutting, the greater the moisture requirement tends to be
- Rotting is not a reliable symptom of over wetting; it can occur when there is too little moisture and almost always occurs when there is not enough light
- Many difficult to root subjects (including *Cotinus coggygria* 'Royal Purple', *Garrya elliptica*, *Syringa*) have high rooting potential but a narrow range of environments in which that potential is expressed
- Easy-to-root subjects are those that tolerate an unusually wide range of environments, often including very low light
- The rooting environment can affect subsequent growth and, thus, the quality of liners and container plants, especially in slower growing plants that do not require much pruning to create a desirable shape

These general conclusions can be combined to optimise the rooting environment of HNS subjects and so provide a good foundation for all subsequent stages of production. Example action points include:

- In nursery situations where light is often difficult to precisely control, aim for slightly higher light levels than the minimum acceptable and provide correspondingly more moisture to avoid water stress. Fog and mist controllers must increase output as the light level increases if water stress is to be minimised
- For plants with a high moisture requirement, supportive high humidity rooting environments should be used; leaf wetting alone will usually not be sufficient to avoid moisture stress and, in turn, poor results

- A suitable combination of high humidity and leaf wetting can be achieved with fog or by enclosing mist under a polythene tent.
- Minimising ventilation to retain humidity leads to high temperatures during sunny weather so adequate shade is essential

Table 14 provides further guidelines relating to specific HNS subjects in terms of their specific environmental requirements.

Table 13. Light and moisture requirements of leafy cuttings of a range of HNS subjects

Environmental conditions	Subject
High moisture requirement	*Acer cappadocicum* 'Rubrum' *Corylus maxima* 'Purpurea' (apical cuttings) *Corylus maxima* 'Purpurea' (non-trimmed proximal cuttings) *Cotinus coggygria* 'Royal Purple' *Elaeagnus pungens* 'Maculata' *Garrya elliptica* 'James Roof' *Pieris* 'Flaming Silver' *Rhododendron* 'Goldflimmer' *Rhododendron* 'President Roosevelt'
Moderate moisture requirement	*Acer palmatum* 'Aureum' *Aubrieta* 'Red carpet' *Aubrieta* 'Greencourt Purple' *Cornus alba* 'Sibirica' *Corylus maxima* 'Purpurea' (leaf trimmed proximal cuttings) *Ceanothus* 'Autumnal Blue'
Low moisture requirement	*Cryptomeria japonica* 'Elegans Compacta' *Convolvulus cneorum* *Daphne x burkwoodii* 'Somerset' *Potentilla fruticosa* 'Tangerine'
High light requirement	*Berberis x stenophylla* *Fremontodendron* 'California Glory'
Widely tolerant	*Forsythia x intermedia* 'Lynwood' *Pieris japonica* 'Little Heath' *Weigela florida* 'Variegata'

Table 14. Guidelines for the propagation and growing on of specific HNS subjects

Subject	Comments
Acer cappadocicum 'Rubrum'	Nearly 100% of soft apical cuttings root in a wet and humid environment ('wet fog' or closed mist)
Aubrieta	Despite being a plant that can grow in dry conditions, cuttings rooted best under moderately heavy mist
Corylus maxima 'Purpurea'	Almost 100% rooting of apical cuttings is possible if leaves are kept moist and humidity is high. Wet fog or enclosed mist is ideal, with about 20% of available light. Non-apical cuttings can also be used and tolerate slightly drier conditions
Cotinus coggygria 'Royal Purple'	100% rooting achievable in a very wet environment at moderate to high light
Cryptomeria japonica 'Elegans Compacta'	Avoid environments that suppress transpiration too much
Elaeagnus pungens 'Maculata'	Needs high humidity and heavy wetting
Fremontodendron 'California Glory'	Avoid excessive shade; during summer 25% of available light should be satisfactory. Ensure the rooting medium is well drained and avoid over wetting
Garrya elliptica 'James Roof'	Given high humidity and generous wetting, nearly 100% of soft apical cuttings root. Fan-distributed fog is probably ideal, with 20% of available light
'Flaming Silver' *Pieris*	Roots best from small cuttings under wet conditions (fog or closed mist)

Mist and high humidity environments

Early mist systems aimed at providing a continuous supply of fine mist in the propagation house, a precursor perhaps to what became better known as fog or high humidity propagation.

The principal difficulty with continuous mist was that it applied more water than was required for rooting leafy cuttings and was, in fact, detrimental. As such, various systems of control evolved, from the use of simple time clocks, through devices called 'evaporating pans', to what became known as the 'electronic leaf', each of which serve to break an electric circuit in order to control the on-off period of the misting. The latter are, of course, not without difficulties and since then light sensors have been used and, most recently, the Evaposensor developed at NIAB EMR.

Mist propagation differs from fogging in that misting produces water droplets with a considerably greater size range in which most are larger than 50 microns. Such large droplets have minimal suspension properties and fall out of the air, leading to cuttings becoming water stressed if the film of water on the foliage is incomplete and humidity drops between mist bursts. Over wetting of the rooting medium can also occur, underlining the need for good control of the mist unit.

Despite progress with high humidity fog propagation, mist units remain the main system used by the industry for the rooting of cuttings, particularly during the spring and summer period.

The mist environment

The principal function of mist is to wet the foliage of cuttings and minimise transpirational water loss by raising the vapour pressure deficit microclimate around the leaf stomata and by using the evaporative cooling effect of leaf moisture. To prevent water stress in cuttings, the vapour pressure inside and outside the leaves should, ideally, be at the same point, and high humidity environments help to achieve this. Turgid cuttings root better and quicker than cuttings that are allowed to wilt. Mist also wets the rooting medium sufficiently for root initiation.

When correctly set up and managed, mist propagation provides leafy cuttings with ideal conditions throughout the rooting process and so enables quick rooting.

Good ventilation and shading to control air temperatures and light levels is important, particularly in summer. Bright sunshine quickly scorches soft cuttings and high temperatures reduce atmospheric humidity, leading to moisture stress in the cuttings and excessive extension growth, which mobilises carbohydrates at the expense of rooting. Very high light intensities also lead to an excessive build-up of carbohydrates within cuttings, which can inhibit rooting.

Preferred air temperatures will vary with situation but 12–15°C will usually suffice, ventilating at 18–21°C, although some references suggest 25°C.

Most heat is required at the base of cuttings for rooting and not in the aerial environment, aside for frost protection in winter. Optimum basal temperatures vary with species. At one point, 21°C was widely recommended for HNS but this is costly and many subjects root readily, but a little slower, at lower temperatures (around 15–18°C) or even without base heat, for example, many conifers and easy rooting shrubs. The standard recommendation is 18–24°C.

Excessive misting will over wet cuttings and deplete their nutrient reserves by leaching and should be avoided. While this can be offset by foliar feeding or 'fertigation' via the mist lines and the use of controlled release fertilisers in the rooting medium, cuttings can still deteriorate, underlining the need for good mist control. Over misting also leads to water run-off from cuttings, saturating the rooting medium and reducing the base temperature. Rooted cuttings should be weaned off and removed from the mist promptly, otherwise they can quickly deteriorate as a result of nutrient leaching. Rooting through into sand beds, can also occur, leading to subsequent growth checks.

A suitable air to water ratio in the rooting medium is critical under mist and, while moisture input can be regulated through efficient environmental control, good drainage in the trays and beds is essential.

Good water quality is essential for mist to work well. Water must be clean and relatively soft as hard water creates unsightly limescale on cuttings, which impedes photosynthesis, raises substrate pH over time and leads to nozzle blockages, thereby reducing efficiency of the mist.

Setting up a mist unit

Mist units can be set up in polythene tunnel structures or glasshouses, preferably the latter as they are usually easier to ventilate to control summer temperatures. They also tend to be less humid and have a more buoyant, easily controllable atmosphere.

Benched mist systems have the advantage of easy access and visibility, particularly when inspecting and picking over cuttings but floor level beds are usually cheaper, make good use of space and are more widely used. Ideally, beds and benches should be around 1.2 m wide to enable cuttings to be easily reached in the centre. Typically, such beds or benches are lined and of a capillary sand bed construction. Sometimes, the beds are also covered with a permeable membrane to control weeds and rooting through. Such surfaces are usually more hygienic and easier to keep clean but can restrict capillary contact and drainage.

The beds or benches should be insulated around the sides and base with 5 cm polystyrene, wrapped in plastic for heat conservation, especially where base heat is used. Heating cables are still used to provide heat although there is some use of heat foils and underfloor heating using hot water piping. Cables are normally laid on a bed of sand or gravel, to a depth of 10–15 cm, allowing a 5 cm space between each loop of the cables. Wire netting placed over the cables provides useful protection and helps spread the heat. Modern sensors placed in the rooting medium near the base of the cuttings provide temperature control.

Basal heat provided by screened heating cables

Basal heat provided by piped hot water

At one stage, open plan porous concrete floors were used with alkathene heat pipes underneath the surface but these are now less common on account of their high cost. However, they offer excellent space utilisation, flexibility, ready access, strength, energy efficiency, cleanliness and easy maintenance.

The layout of the mist jets varies but usually they are either attached to standpipes arising from the base of the bed or suspended above the bench or bed. Either way, each of the jets must be at the same level. While different types of mist jet are now available, most produce a circular spray pattern, such patterns should overlap to avoid dry corners. Mist heads should be run in a single line down the beds or benches rather than alternated, which wastes water.

Bed mist system with risers

Traditionally, an automatic or 'wet' leaf placed between the cuttings was used to control the frequency of the mist but these have been superseded by time controls, light sum sensors and, most recently, the Evaposensor.

Mist units should be serviced regularly to maintain their efficiency. Misting jets should not be allowed to become blocked; they should be removed and cleaned at least annually and any probes and mist control equipment inspected.

Propagation programme

Mist facilities can be expensive to set up and run so to be cost-effective they need to be used throughout the year or at least most of it. Using an average rooting period of two to six weeks depending on species, it is feasible to put six to eight batches of cuttings through a mist unit during a year. However, there is likely to be a peak during the April to August period requiring careful management and prompt weaning of rooted material.

Forcing stock plants enables earlier cuttings to be taken, for example, of subjects such as *Acer palmatum*, deciduous *Azalea*, *Clematis*, *Cotinus*, *Exochorda* and *Syringa,* and helps to even out peaks. Many HNS species can also be readily rooted throughout the autumn and winter period, including evergreen species and many conifers.

Grey or hairy-leaved subjects such as *Senecio* (syn. *Brachyglottis*), *Santolina* and *Lavandula* dislike continually wet foliage and usually root well under polythene or glass.

While most nurseries will have their own mist propagation programme, an example is shown overleaf in Table 15.

Table 15. Year round mist propagation programme

Month	Subjects
January	Evergreens and conifers, e.g. *Chamaecyparis*, X *Cupressocyparis leylandii*, *Ilex*, *Mahonia*, *Thuja*, etc.
February	Evergreens and conifers, e.g. *Chamaecyparis*, X *Cupressocyparis leylandii*, *Ilex*, *Mahonia*, *Thuja*, etc.
March	Evergreens, conifers, softwood cuttings (forced), e.g. *Acer*, *Azalea*, *Cotinus*, *Exochorda*, *Syringa*, etc.
April	Softwood cuttings (forced) continued
May	Softwood cuttings, shrubs, climbers, alpines, herbaceous
June	Softwood cuttings continued
July	Softwood and semi-ripe cuttings, e.g. *Choisya*
August	Semi-ripe cuttings, e.g. *Azalea* (evergreen), *Camellia*, *Ceanothus*, *Eleaegnus*, *Garrya*, *Hydrangea*, *Viburnum tinus*, etc.
September	Semi-ripe cuttings continued, e.g. *Choisya*, *Ceanothus*, *Elaeagnus*, *Garrya*, *Pyracantha*, *Skimmia*, *Viburnum*, dwarf conifers, etc.
October	Semi-ripe cuttings continued, evergreens and conifers
November	Semi-ripe and hardwood cuttings, e.g. *Juniperus*, *Taxus*, etc.
December	Semi-ripe and hardwood cuttings, e.g. *Juniperus*, *Taxus*, etc.

The fog environment

Fogging is the distribution of very small water droplets through the propagation environment to create a constantly high humidity, usually in the order of 95–100%. Its principal objective is to produce a high humidity environment without over watering the rooting medium or leaching nutrients from the foliage of cuttings, a common difficulty with some mist systems. The more constant humidity of fog also helps avoid the cyclic humidity patterns associated with mist, which can stress unrooted cuttings, particularly those of a soft, leafy nature. As such, fogging is primarily a spring and summer system in the UK and is especially useful for the early season rooting of more difficult plant subjects.

The air-borne water droplets that create the fog are minute (typically, down to 10 microns or less in size) and their dispersal raises the humidity of the aerial environment to the point where there is an excess of water droplets suspended in the air, hence the term 'fog'. Such droplets float rather than fall from the air and, because of their large surface area to volume ratio, they readily evaporate and cool the air. They also create and maintain a very thin film of water over the complete surface area of the cutting, cooling the surrounding air and reducing transpirational water loss as they evaporate.

Fogging systems

Fogging equipment is usually based on one of the following systems:

- Ventilated fog (centrifugal system). With this system, large volumes of air are drawn by a fan across water broken into small droplets either by centrifugal force along spinning rods or a spinning disc, and blown through the propagation area. This approach confers the advantage of cooling but uses relatively large volumes of water of varying droplet sizes, which produces a marked gradient in relative humidity and can over water due to fall-out near the fogging unit as well as creating considerable air turbulence. As such, they are less suitable for weaning micropropagated material. This system is usually the cheapest method of fogging, no compressor being required
- Pressurised water fog (high pressure system). This fog is produced by forcing water at very high pressures through micro nozzles from overhead suspended lines. They are usually more expensive but produce a uniform fog of small droplet size (10 micron) capable of suspension in the air
- Pressurised air/water systems (low pressure/pneumatic system). In this system compressed air and water are brought together in specialised jets creating a shockwave that disrupts the water and produces relatively fine droplets. The individual nozzles and associated compressors can be relatively expensive

Control systems

Successful fogging depends on good control to maintain the requisite humidity levels and avoid over fogging and, in turn, excessively wet foliage. Excessive fogging leads to coalescence of the fine droplets, fall-out and wet leaf and rooting media surfaces, not unlike mist.

Several control systems are available, ranging from simple timer units through to interval controllers that humidify the air for set periods, various types of humidistats and aspirated humidity controllers that are suitable for different fogging systems.

At HRI Efford, a time clock control gave poor results in the variable weather patterns of the UK and, while the humidistats of the time were an improvement, there was a time lag in response to changing conditions. An electronic humidistat able to maintain a very narrow range of humidities gave the most promising results.

Shading

Leafy cuttings in a nearly saturated atmosphere lose water very slowly, although transpirational water loss does not entirely stop. Light falling on leaves raises leaf temperature above that of the surrounding air, such that they will lose some water even in a fully saturated environment. In such a humid atmosphere, little of the light energy absorbed by the leaves is lost through evaporative cooling, so leaf temperature can be relatively high, even damaging. Adequate shading, around 50% in the summer, to reduce light and heat and so avoid water stress is, therefore, essential in fogged systems.

Work at HRI Efford with a pressurised air/water fog system found that, even with a 55% permeable shade screen across the propagation house, temperatures in excess of 35°C were recorded. As only limited ventilation is possible with fog systems, at HRI Efford up to 20% vent on the leeward side of the glasshouse and 10% on the windward side proved an acceptable compromise. Despite the high temperatures, cutting material appeared to acclimatise to the conditions and rooted well.

Research

Early work at HRI Efford comparing fogging with mist for summer and autumn propagation indicated faster rooting and earlier growth from cuttings rooted under fog. Cutting quality was also better as foliage leaching was reduced. Further work at the former GCRI found that the stomata on leaves of fogged cuttings were more open than those under an open mist, so that entry of carbon dioxide for photosynthesis was less restricted. Consequently, fogged cuttings gained dry weight faster, in spite of reduced light. Their water balance was also slightly superior to that of cuttings in closed mist and considerably better than in open mist. While previous studies had shown that root initiation seldom relates to dry weight gain, in summer, cuttings with the best water status usually root faster and to a higher percentage.

Rooting trials with ‘wet’ (closed mist and fog) and ‘dry’ (open mist) systems at GCRI using a pressurised air/water fogger found that conifers (*Chamaecyparis lawsoniana* ‘Tamariscifolia’ and *X Cupressocyparis leylandii* ‘Robinson’s gold’) and broadleaf evergreens (*Buxus sempervirens*) performed less well in fog than in open mist. However, fog produced better rooting among soft leafy cuttings of subjects such as *Acer palmatum*, *Cotinus coggygria*, *Cornus alba* and *Magnolia* x *soulangiana* than open mist and similar, rooting to closed mist.

Merits and limitations of fogging systems

The merits and limitations of fog propagation relative to mist can be summarised as follows:

Merits

- Larger cuttings may be rooted, particularly those cuttings with large leaf blades, as fogging has been found to keep cuttings in better condition until rooting has occurred
- Cuttings can be taken earlier in the season when softer and easier to root, due to the more supportive, higher humidity environment provided by fog
- Rooting is sometimes faster, with higher percentage takes
- Premature leaf-drop due to nutrient leaching and water stress is lessened compared to mist
- Rooting media is less likely to become waterlogged (reducing the prospect of cuttings damping-off)
- Significantly less water is required and water particles are more evenly dispersed
- The high humidity environment created by fog is more supportive than mist and so ideal for weaning micropropagated material

Limitations

- Achieving uniform distribution of fine fog droplets can be difficult and marked variations in rooting and cutting survival can occur, although researchers at HRI Efford found that lining their propagation house with polythene reduced the rate of fog dispersion. Installing ancillary ventilation fans to gently move the fog around may also help
- Controlling high temperatures can also be difficult as fog is essentially a closed system. This can be a particular problem in non-ventilated systems, underlining the need for adequate shade screening in summer. Ventilated high humidity fogging units that draw cool air into the propagation area and continually replenish the moisture content of the air enable ventilation to take place. As such, the combination of cool air and ventilation creates lower ambient temperatures
- Generally, fog is a less comfortable environment to work in due to the high humidities and temperatures although high pressure systems capable of producing water droplets of 10 microns in size create a ‘dry’ fog which is more comfortable (such systems are also more suitable for winter propagation)
- Only water drawn from a clean, direct mains supply (avoiding storage tanks) can be used, to help safeguard staff from contracting *Legionella* via inhalation of the fog. Enclosing fog units within high polythene tents provides a further safeguard
- Rooted cuttings require earlier weaning to prevent growth becoming drawn and soft under high temperatures

Aftercare

In high humidity environments such as mist or fog, *Botrytis* infection of leafy cuttings can readily occur and requires prompt control. Although ventilation and well-controlled mist environments that reduce over wetting help, cuttings should be checked daily and any decaying material removed promptly.

Fungicide sprays may also be required to control disease outbreaks, although a routine programme is seldom justified if the mist environment is well managed.

Weaning should start once cuttings are adequately rooted, roots should be at least 2 cm long. Usually, the mist is either reduced gradually or the rooted cuttings are removed to a separate weaning bed, bench or house, to enable the continued rooting of other cuttings in the mist.

Once fully rooted and acclimatised to ambient conditions, the cuttings may be transferred elsewhere to await sale or potting on, unless they have been direct struck into final containers.

The inclusion of controlled release fertilisers in the rooting medium became standard practice following successful trials at HRI Efford and provides important post-rooting nutrition to maintain cutting quality until potting, although preformed plugs with controlled release fertiliser are now widely used too.

Similarly, the timely application of soluble feeds helps maintain cutting quality, including the use of high phosphate feeds ahead of potting to trigger root development and so, in turn, rapid plant establishment.

Crucially, cuttings must not become starved or rootbound otherwise plant quality will suffer and establishment will be much slower following potting.

The role of the Evaposensor

Even with well-managed mist or fog systems, water stress among leafy cuttings may still occur if the control system, usually based on a timer, electronic leaf or measurement of solar radiation, fails to adequately match the misting or fogging frequency to the varying needs of the cuttings.

The Evaposensor, developed by Dr Richard Harrison-Murray at NIAB EMR as a research tool for controlling mist and fog environments, possesses wet and dry artificial 'leaves', enabling the detection and control of the evaporative demand on cuttings in a reliable and reproducible way. Crucially, it enables optimum conditions to be quantified and reproduced in a way that is not possible with any other type of mist control.

At NIAB EMR, it contributed to the successful propagation of difficult-to-root HNS subjects, including *Acer cappadocicum*, *Acer palmatum* cultivars, *Corylus maxima, Cotinus coggygria, Garrya elliptica* and some *Pieris* and *Rhododendron* cultivars. It has since been commercialised and has been available for use by growers for many years.

The Evaposensor consists of two temperature sensing 'leaves' containing platinum resistance temperature sensors. One 'leaf' remains wet via a wick connected to a distilled water reservoir and the other 'dry leaf' is wetted periodically by bursts of mist or fog. It is positioned just above the height of the cuttings, where it is influenced by the mist/fog, solar radiation, air temperature, humidity and air movement – all the factors that normally affect the rate of transpirational water loss from cuttings.

It requires an interface electronic controller to enable output from the wet and dry 'leaves' to trigger mist or fog bursts, either in conjunction with existing timers or as a standalone controller.

The Evaposensor works in the following way:

- The 'wet leaf' is generally cooler than the 'dry leaf' due to evaporative cooling
- The temperature difference (°C) between the two is known as the wet leaf depression (WLD)
- WLD is proportional to potential transpiration and so potential water stress on cuttings
- During misting or fogging, the 'dry leaf' becomes wet and the WLD falls to near 0°C, mimicking the effect of mist on transpiration
- After a burst of mist or fog, as the 'dry leaf' dries out, the WLD rises until the set point on the controller is reached and another mist or fog burst is triggered
- The WLD set point (the maximum WLD before a mist burst occurs) represents a level of cutting support that can be reproduced across different facilities, nurseries and seasons. Different HNS species may require different set points but a compromise set point is required where a wide range of subjects is involved, particularly when sharing the same propagation bed

The system applies the amount of mist or fog needed to limit transpiration to the level set on the controller, taking into account the background environment.

The Evaposensor helps detect and control the evaporative water demand on cuttings in a reliable and reproducible way

Research involving the Evaposensor

AHDB Horticulture project HNS 159: ***Nursery stock propagation: Nursery evaluation and demonstration of the Evaposensor towards its commercial availability as a mist controller***, evaluated the technical performance of the Evaposensor on commercial nurseries against their existing mist control systems and sought to develop an electronic interface to enable the technology to be commercially adopted. The comparative performance of the Evaposensor was also tested in terms of rooting leafy cuttings of a range of HNS subjects.

Trial treatments and effects on the rooting of cuttings

In the first year of trials (2007–2008), the Evaposensor was compared with the chosen nursery's own timer-based control system and, throughout the trial, it maintained consistently low stress (low WLD) environments compared to the timer system, where the WLD fluctuated significantly.

The evaluation of the Evaposensor and interface controller continued in year two (2008–2009), with a wider range of HNS species on an additional two nurseries with different ambient environments.

For many subjects, rooting results were similar between the Evaposensor and timer control (averaging 77% for the former and 74% for the latter system). However, some subjects (notably, *Berberis darwinii* 'Compacta', *Hydrangea petiolaris, Prunus cerasifera* 'Spring Glow', *Solanum crispum* 'Glasnevin', *Spiraea arguta, Spiraea japonica* 'Goldflame', *Tecrium fruiticans* 'Compactum' and *Viburnum sargentii* 'Onondaga') did benefit from the, typically, higher amounts of mist provided via the Evaposensor and gave noticeably improved rooting.

Some subjects rooted slightly less well under the Evaposensor treatment, including *Convulvulus cneorum*, *Ceanothus* (various cultivars), *Eleaegnus* 'Quicksilver' and *Halimiocistus sahucii*.

As a result of the wide range of subjects included under each of the mist environments, the treatment set points were also unlikely to be optimal for all of them.

Year one conclusions (2007–2008)

- The automatic adjustment of mist to light, temperature and humidity was considered a great advantage. It was also accepted that the manual adjustment of timer settings can never be as effective. Although the Evaposensor applied more mist to the cuttings, it crucially applied less mist during dull or cool weather conditions
- While different set points may be required for optimum results with different species (the one used in the trial was a compromise for the wide range of subjects involved on the same bed), it can be used more reliably by defining a WLD set point that automatically takes account of weather changes and differing ambient aerial environments between propagation units
- Where a range of HNS subjects is involved, a 1–1.5°C WLD set point on the Evaposensor interface or controller is likely to be a good starting point (using a mist burst of around two seconds)
- The Evaposensor showed considerable promise as a flexible and user-friendly system for controlling mist in propagation environments

Year two conclusions (2008–2009)

During this phase of the project, the Evaposensor controller was developed further, such that it was available as a commercial product.

- Subjects showing a significant improvement (over 10%) in rooting included *Ceratostigma willmotianum* 'Forest Blue', *Choisya ternata, Escallonia* (various cultivars), *Halimium, Olearia* cultivars, *Pittosporum tenuifolium, Prostanthera cuneata* and *Vinca minor* cultivars
- Those that rooted less well under the Evaposensor included *Convulvulus cneorum*, *Halimiocistus sahucii, Prostanthera* 'Mint Royal', Rhamnus alaternus '*Argenteovariegata* and *Weigela* 'Red Trumpet'
- Overall, the most significant percentage rooting benefits occurred where the standard system failed to apply sufficient mist during high evaporation demand periods and cuttings were stressed, although some subjects disliked the extra wetting applied to foliage by the Evaposensor during hot conditions, including *Convulvulus cneorum* and *Halimiocistus sahucii* (species with hairy or downy leaves are likely to hold water for longer and so benefit from a drier regime)
- For most subjects, there were no obviously large differences in terms of speed of rooting, although at one nursery site, with several subjects including: *Artemisia* 'Powis Castle', *Cistus* 'May Snow', *Euonymus japonicus* 'Duc d'Anjou' and *Vinca minor* 'Illumination' (all two to three weeks quicker) and *Euonymus fortunei* 'Harlequin' and *Polygala myrtifolia* (seven and eight weeks quicker, respectively), there was clear evidence of faster rooting under the Evaposensor regime
- More shoot growth from plugs was also observed in the Evaposensor treatment for these and other subjects during and shortly after their time under the mist

Commercial testing and development

The development of a commercial mist control unit harnessed several features that enhanced the versatility of the Evaposensor; it could be used either as a standalone controller operating a single solenoid valve or be linked to an existing timer or sequencer to control multiple beds.

The Evaposensor was tested at three commercial nurseries as part of AHDB Horticulture project HNS 159a: ***Promotion and dissemination of Evaposensor sensor mist control on nurseries***, and proved easier to manage, compared to the traditional wet leaf mist control normally used at two of the sites, which tended to apply too much mist. At the third nursery, the Evaposensor also required less adjustment and provided an easier to manage environment for weaning micropropagated material compared with their usual light-sum system.

Experience on the third nursery site did not suggest that the Evaposensor was an improvement on their existing mist technology. However, in this case, a very dry regime was favoured, partly in response to the range of plant material produced and partly because of a lack of a positively drained standing base. A sophisticated mist control regime based on light-sum and humidity, using a climate control computer had already been adopted by the nursery.

Evaposensor mist controllers are now available to growers, which feature a digital display of WLD to indicate current status, built-in timers for the control of both the burst length and the minimum interval between bursts, and a standalone mist controller or an interface to existing equipment. An analogue output, which expands the options of integration with other equipment, had already led to success in automatic scheduling of irrigation.

During nursery testing, staff readily grasped the basic concepts of Evaposensor control and the mist control unit. Some nurseries were content to leave the WLD set-point alone, allowing the Evaposensor to compensate for day-to-day variations in weather and season. Others preferred to exploit the convenience of the calibrated set point control to fine-tune conditions to suit particular species, season, stage of rooting, etc. Where capillary drainage is limited or a particularly dry regime is required, the 'interval' control can be useful to set an upper limit on misting.

Financial benefits

Any financial benefits primarily depend on the scale of overall improvement in the percentage of useable cuttings produced and any savings in labour. Other benefits are less straightforward to calculate financially but still have a monetary value, such as ease of management, ability to rely less on skilled staff (especially for weekend or holiday cover) and the opportunities for propagating new or difficult cultivars that would otherwise have to be bought in.

So far as labour savings are concerned, assuming an average 12% increase in rooting is achieved, for a propagation unit producing some 200,000 cuttings per annum, around £1,000/year could potentially be saved from wasted inputs (including preparation and handling of cuttings not rooting). Or, considered another way, a 12% increase on 200,000 liners with an average unit value of 75p would equate to an increase of approximately £18,000 in financial output.

Polythene systems

Many HNS subjects can be rooted without mist, using simple polythene systems, usually, but not necessarily with, base heat, particularly during the autumn and winter period. Typically, the polythene cover is suspended over a hoop or frame to provide an air buffer around the cuttings, but it can be placed directly over the cuttings too (warm bench and plastic system). Benches or floor level beds are used and constructed in much the same way as a mist system. In fact, some growers deploy a hybrid of the two, using well-shaded closed mist system for summer propagation of soft leafy cuttings and polythene without the mist for the autumn and winter rooting of evergreens and conifers, which prefer a drier regime. Fleece covers are often used for additional shade or heat retention.

Warm bench and plastic system

With this system, the cuttings are directly covered with a thin (around 20–25 micron) transparent polythene film following insertion. Usually, the sheet is clear but

Case study 5: P&S Nursery Stock

Fine tuning mist propagation

P&S Nursery Stock in Cambridgeshire produces a wide range of pot liners and plug plants each year for sale to the trade. Much of the propagation work is undertaken during the spring and summer months using soft and semi-ripe leafy cuttings rooted under open mist, although some species are struck during the autumn and winter period, mainly evergreens.

Two open mist beds are used, one either side of a central pathway, in a walk-in polythene tunnel, shaded during the summer months. Most rooting is done in plug trays using a ready-mix rooting medium of coir, bark and perlite, with a powder hormone treatment for the cuttings in most cases.

While mist has usually worked well for the nursery, recurring difficulties had been encountered with over wetting (despite electronic leaf, timer and light sensor controllers being tried), resulting in the rotting of cuttings leading to, in some cases, heavy losses.

In a further attempt to match misting frequency closer to the needs of the cuttings, reflecting more accurately changing light levels, humidity, temperature and air movement during the day, the nursery trialled an Evaposensor with summer propagation during 2010, having followed HNS 159 and earlier work at EMR with interest and been encouraged by the results. So far, the Evaposensor has delivered good results, following initial teething problems of finding the appropriate WLD set point, given the wide range of HNS species being rooted at any one time on the same bed.

Nursery owner Paul McKarry comments, "It would be hard to say the Evaposensor has made a radical change to our mist propagation, however, it has given better control over the system in terms of leaf wetting and less over wetting of rooting substrate. Rooting has increased in general by 10–20%."

Polythene tent systems, whereby the polythene (or fleece) is raised above the crop, are usually easier to manage than contact polythene

a white film is necessary for summer propagation unless shade screening or netting is used (these may also be necessary with a white film during very bright periods). Shading is in fact usually required from late winter onwards, as even low sunlight can quickly increase temperatures under the film to damaging levels. A maximum-minimum thermometer should be set within the cuttings for temperature monitoring. The edges are sealed using laths or by tucking the film underneath the plug trays or pots used for rooting.

Contact polythene quickly 'fogs up' once cuttings are covered to create the humidity required for successful rooting

Once drawn over the cuttings, the film quickly 'fogs up' with condensate such that the cuttings become enclosed within a saturated atmosphere that prevents them wilting.

Most recently, the commercial film XL ThermaProp has been developed for HNS propagation, white for summer and clear for winter use. This material combines heat retention and even temperature distribution with an internal anti-drip coating to avoid over wetting of cuttings.

While this system offers a useful low cost alternative to mist propagation, particularly during the autumn and winter periods, it does demand especially careful management. Shading is crucial and cutting material should be checked daily. Decaying cuttings must be removed promptly, otherwise *Botrytis* will quickly follow. The film should be peeled back regularly for a detailed inspection and to vent the cuttings.

Once rooted, usually in plug trays, the cuttings should be weaned by gradually slitting or removing the plastic film. This must be done carefully as sudden exposure to bright sun will lead to drying out and deterioration of the cuttings. Alternatively, rooted material can be moved to another bed to enable the continued rooting of later struck cuttings. Base heat is gradually reduced as weaning progresses.

Some propagators feel that cuttings rooted in this way remain in better condition than those rooted under mist, due to an absence of nutrient leaching, although they can be slower to root. Table 16 (overleaf) lists a range of HNS subjects suitable for warm bench and plastic propagation, while Table 17 (overleaf) compares and contrasts the warm bench and plastic system with mist propagation.

Table 16. HNS subjects suitable for cutting propagation under a warm bench and plastic system

Month	Subjects
January	Various conifers, including: *Chamaecyparis, Cupressus, X Cupressocyparis leyandii* and *Juniperus*, etc.
February	Conifers continued, also various evergreen shrubs, including: *Elaeagnus, Garrya, Ilex* and *Rhododendron* (dwarf species and cultivars), etc.
March	Conifers and evergreens continued
April	Deciduous shrubs including: *Azalea, Magnolia*, etc.
May	Deciduous shrubs continued, including: *Azalea, Magnolia, Cotinus*, etc.
June	Deciduous shrubs continued, including: Cornus (dogwood species) *Cotinus, Deutzia, Forsythia, Hypericum, Philadelphus*, species roses, etc.
July	Deciduous shrubs continued, including: *Magnolia, Pieris, Ribes, Spiraea etc.* Some evergreens including: *Azalea, Camellia,, Cotoneaster,* etc.
August	Various deciduous and evergreen species, including: *Azalea, Camellia, Cotoneaster, Pieris, Spiraea, Viburnum tinus*, etc.
September	Evergreens including: *Azalea, Berberis, Camellia, Pyracantha, Viburnum*, etc.
October	*Cupressus, Ilex, Mahonia, Pittosporum, Rhododendron* (hardy hybrids), *Thuja*, etc.
November	*Berberis* (evergreen), *Chamaecyparis, X Cupressocyparis leylandii, Cupressus, Ilex, Mahonia, Pittosporum, Thuja,* etc.
December	Various evergreens and conifers continued

Table 17. Advantages and disadvantages of a warm bed and plastic system compared to mist propagation

Advantages	Disadvantages
Cheaper and easier to install No nutrient leaching from cuttings More constant humidity pattern giving rise to less water stress Less risk of over wet rooting media Suitable for a range of HNS subjects, particularly for autumn and winter propagation Better quality rooting	Greater care and closer attention is required in relation to hygiene, shading and weaning High summer temperatures can be a problem, especially with soft, leafy cuttings Less suitable for spring and summer propagation of soft leafy cuttings Slower rooting

Low tunnels

A wide range of HNS species can also be rooted from semi-ripe cuttings under low polythene tunnels situated outdoors, to provide well-rooted liners within a year from propagation. This system is well suited to cheaper, high volume lines as it is low risk, low cost and doesn't require highly skilled labour. It also enables expensive heated, mist facilities to be used for more difficult subjects and liners produced in this way are usually strong and sturdy, requiring less weaning or 'hardening off' than mist propagated material. However, rooting is slower and there is less control of growth, which may complicate scheduling requirements.

The tunnels are formed from simple galvanised wire hoops used to support opaque white polythene (38 micron), pushed into the ground (usually, to a depth of 30 cm) at 1 m intervals, with eyelets to secure the tying material. Double hoops are used at the ends of the tunnels to provide greater strength when the polythene is stretched tight.

The beds are usually 1 m wide and of any desired length, although very lengthy constructions hinder materials handling and access. A rooting medium (typically, peat with grit or bark) is laid over the soil to a depth of 7 cm to form the beds and left loose to enable easy insertion of the cuttings, although it can be worked into the soil as cuttings, are inserted to avoid it drying out. Usually, the mix is then topped with a 2 cm layer of coarse sand or grit to ensure good drainage and aeration around the neck of the cuttings.

Low tunnels provide a fairly humid atmosphere and protection from desiccating winds. There is little by way of frost protection, although crops propagated in this way are usually hardy. An overhead irrigation line can be included within the tunnel to bolster humidity and provide post-rooting irrigation, particularly on light land but, for many crops, this is seldom necessary if the soil is a deep, well drained but moisture retentive medium loam. Shallow soils are best avoided as they can dry out rapidly.

Traditionally, cuttings propagated with this system are classified as semi-ripe and inserted during September and October (deciduous subjects earlier, in midsummer).

A wide range of mainly evergreen but also some deciduous subjects can be successfully rooted using this system, including species and cultivars of: *Aucuba japonica, Berberis, Buddleia davidii, Caryopteris, Cistus, Escallonia, Forsythia, Griselinia littoralis, Hypericum, Lavandula, Ligustrum, Lonicera pileata, Olearia x scilloniensis, Osmanthus heterophyllus, Philadelphus, Potentilla,* evergreen *Prunus* species, *Rosmarinus, Rubus, Santolina, Senecio* (syn. *Brachyglottis*), *Viburnum tinus* and *Vinca*.

Rooted deciduous material can usually be lined out or potted from autumn onwards, while evergreen material normally remains in situ, to root through the autumn and winter.

Sun tunnels

The sun tunnel (so-called as it relies solely on heat provided by the radiant energy of the sun) evolved from the low tunnel system but was reviewed and improved at HRI Efford during the early 1980s. Essentially, it is a low tunnel with an overhead misting line to increase humidity levels for summer propagation of softwood and semi-ripe cuttings.

The HRI Efford work showed that earlier insertion, lower cutting populations and improved nutrition, using controlled release fertilisers, largely overcame many of the problems associated with the original concept and dramatically shortened the propagation period. This created opportunities for propagating a wider range of species and for producing better quality plants.

Sun tunnels are constructed in much the same way as low tunnels but with the addition of an overhead misting line along the ridge (trials with leafy cuttings showed this to be more reliable than simply covering the cuttings with an extra layer of polythene). For additional irrigation of rooted cuttings, seep hose irrigation or similar is normally used.

Development work at HRI Efford used a 50:50 peat and sand mix with controlled release fertiliser (1–2 kg/m^3 of a 12–14 month product), incorporated with the underlying soil to give a suitably textured rooting medium 20 cm in depth, above soil level. Granulated pine bark can also be used.

The most suitable HNS subjects for summer propagation under sun tunnels are deciduous shrubs that root readily from softwood or semi-ripe cuttings, taken between late May and the end of June, to enable maximum growth in the first season. Typically, cuttings are around 10 cm in length, with the lower leaves removed. Shoot tips and floral buds should be removed to encourage well-branched growth once rooted. As a general guide, cuttings should be spaced at 10 cm x 10 cm.

The cuttings should be covered with opaque white polythene (38 micron) that is secured to the sides by wooden laths. Additional protection (20–30% shade netting) is generally required to prevent scorching of soft or very sensitive material. Mist bursts need to be well controlled to ensure cuttings do not dry out and scorch.

At HRI Efford, young plants established and grew away earlier when lined out or potted on in spring compared to those transplanted or potted on the previous autumn. The benefits of stronger root and shoot growth and improved branching from insertion at a wider spacing with controlled release nutrition in the sun tunnels continued in the field.

If the rooted cuttings are to be overwintered in situ, then the shade cloth or suitable windbreak netting, should be placed back over the tunnel frame from late November onwards to provide a degree of winter protection, especially from cold, desiccating winds. Tender subjects are best lifted during the autumn, potted and overwintered under protection.

Generally, for ease of handling and to promote further branching, most species will require trimming before lining out or potting, and again during the growing season.

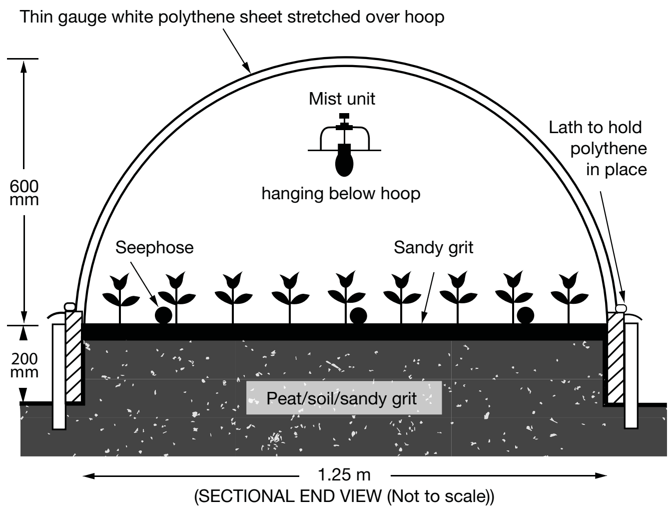
Table 18 overleaf outlines a generic annual production schedule for HNS using sun tunnels.

The HRI Efford work also showed that a range of evergreens and conifers could also be successfully rooted in sun tunnels (with the misting line replaced by a layer of thin gauge clear polythene, supported just above the cuttings) from autumn or spring insertions. Thereafter, the tunnel can be left undisturbed until the following June, aside of occasional checks for moisture, weeds and rooting progress. A white polythene material (shaded in the summer) is used to cover the tunnel and seep hose or similar for post-rooting irrigation.

Once sufficient rooting has developed (usually by midsummer), the inner cover can be removed to begin the weaning process, followed by the top cover a few weeks later, retaining the shade net as necessary to minimise plant stress.

Well-rooted liners should then be ready for potting or lining out in the autumn. Table 19 (overleaf) lists a range of HNS subjects that have been rooted successfully when taken as early summer cuttings in sun tunnels.

Other subjects successfully rooted on commercial nurseries from summer cuttings include: *Berberis thunbergii atropurpurea* 'Nana', *Ribes sanguineum* 'Pulborough Scarlet', *Rosa rugosa* 'Frau Dagmar Hastrup' and *Spiraea bumalda* 'Goldflame'.



Sun tunnels are a cost effective way of propagating a range of HNS subjects

Table 18. Production schedule for sun tunnels using the HRI Efford improved system

April – May	June	July – September	October – November	December – January	February	March – April
Bed preparation	Cutting insertion	Propagation (mist)	Lifting for field planting or potting	Optional: Overwintering in situ	Lifting for cold storage	Lifting for field planting or potting

Table 19. Production schedule for sun tunnels using the HRI Efford improved system

Summer cuttings (May to June insertion)	
Azalea japonica 'Blaauws Pink'	*Lonicera nitida* 'Elegant'
Azalea japonica 'Blue Danube'	*Magnolia x soulangeana*
Berberis darwinii	*Philadelphus* 'Burfordensis'
Berberis x ottawensis 'Purpurea'	*Philadelphus* 'Virginal'
Berberis x stenophylla	*Physocarpus opulifolius* 'Luteus'
Camellia x williamsii 'Debbie'	*Potentilla fruticosa* 'Katherine Dykes', 'Red Ace' and 'Tangerine'
Clematis montana	*Pyracantha* 'Orange Glow'
Cornus alba 'Elegantissima'	*Ribes odoratum*
Cornus alba 'Sibirica'	*Ribes sanguineum* 'King Edward VII'
Cornus alba 'Spaethii'	*Rosa rugosa* 'Scabrosa'
Cornus stolonifera 'Flaviramea'	*Rhododendron* 'Cilpinense'
Cotinus coggygira 'Royal Purple'	*Senecio greyi* 'Sunshine'
Cotoneaster conspicuus	*Skimmia japonica* 'Foremanii'
Cotoneaster horizontalis	*Spiraea x billardii* 'Triumphans'
Cotoneaster 'Cornubia'	*Spiraea nipponica tosaensis*
Cytisus x praecox	*Spiraea x vanhouttei*
Deutzia scabra	*Stephanandra incisa*
Deutzia scabra 'Plena'	*Stephanandra tanakae*
Erica carnea 'Springwood White'	*Symphoricarpos albus*
Forsythia 'Lynwood'	*Symphoricarpos x chenaultii* 'Hancock'
Hebe 'Autumn Glory'	*Viburnum x bodnantense* 'Dawn'
Hibiscus syriacus 'Ardens'	*Weigela* 'Bristol Ruby'
Hydrangea macrophylla 'Draps Pink'	*Weigela* 'Eva Supreme'
Hydrangea macrophylla 'Madame J de Smedt'	*Weigela florida* 'Variegata'
Hypericum calycinum	*Weigela* 'Majestueux'
Hypericum 'Hidcote'	
Kolkwitzia amabilis	
Autumn or spring cuttings (October or March insertion)	
Berberis x stenophylla	*Mahonia japonica*
Chamaecyparis lawsoniana 'Ellwoodii', 'Ellwoods Gold', 'Allumii', 'Columnaris' and 'Stardust'	*Olearia macrodonta*
Chameacyparis pisifera 'Squarrosa Sulphurea'	*Osmanthus delavayi*
X Cupressocyparis leylandii (clone 2) and 'Castlewellan'	*Prunus laurocerasus* 'Otto Luyken' and 'Zabeliana'
Euonymus fortunei 'Emerald Gaiety', 'Silver Queen' and 'Variegatus'	*Skimmia japonica*
Ilex aquifolium 'Handsworth New Silver'	*Thuja plicata* 'Zebrina'
	Viburnum tinus 'Eve Price'

Cold frames with and without plastic

Many conifers and evergreen HNS subjects (a similar list to those that can be rooted under low tunnels) can be rooted cheaply and successfully in cold frames from semi-ripe cuttings during the autumn, direct stuck into beds of well-drained rooting medium with controlled release fertiliser, for lining out or potting the following spring. They can also be used for a wider range of subjects, including the spring and summer propagation of easy rooting subjects, with the use of thin gauge (20–25 micron) polythene laid directly over the cuttings (for lining out or potting from autumn onwards).

Summer shading is essential and frost protection will be required in winter. For winter propagation, the use of plastic is unnecessary, although there are exceptions, notably, for example, *X Cupressocyparis leylandii* and *Pittosporum*.

Junipers struck during April and covered with plastic are known to root readily when propagated in cold frames and are usually ready to come out during June for growing on, to be replaced by a range of HNS subjects. Shading is especially important with April and June insertions. Semi-ripe cuttings of *Lavandula* also respond well to direct insertion into cold frames during late August and September.

A variation of the cold frame with plastic system is one using double glazed frames, whereby the frame lights (usually, a standard 'Dutch-light' type) are insulated with 38 micron polythene. The cycle of propagation follows that of the cold frame with plastic, starting with easy rooting evergreens and conifers during September and October. HNS subjects known to root well at this time in frames include *Cotoneaster* and *Ilex* species and cultivars, and a wide range of conifers, including *Chamaecyparis lawsoniana, X Cupressocyparis leylandii, Cryptomeria, Taxus* and *Thuja.* Well-rooted liners of such material should be ready for lifting and growing on from late spring onwards, although June is usually preferred for conifers, given they are often a little slower.

Semi-ripe cuttings of *Juniperus* will normally root within 12 weeks with this system and a range of semi-ripe shrub cuttings can be struck throughout June and July, for example, *Clematis*, *Cotoneaster*, *Hedera, Philadelphus, Viburnum* and various heathers.

All cold frames should be constructed on well-drained land sheltered from cold, drying winds and preferably with a warm, southerly aspect.

Cuttings in the open ground

This is a relatively easy method of propagation from mainly hardwood cuttings, which offers a simple, low cost option for a range of species. Sites should be well drained and sheltered from strong, cold winds. Frost pockets should be avoided and the land free from perennial weeds. Lighter soils such as sandy-loams or silt-loams are ideal, combining good natural drainage in winter with moisture retention post-rooting in summer. Sheltered sites also enable the ground to warm up quickly in spring and dry out sufficiently to allow prompt lining out of rooted cuttings in spring; a south-facing aspect is ideal.

Nodal cuttings of well-ripened shoots are normally used, around 20–25 cm in length and struck from October onwards. Bush fruits and rose species for rootstocks usually have their lower buds removed to discourage growth from below ground level. Hormone rooting treatments are not usually required, although 0.8% IBA can be considered.

Cuttings should be graded and only the thickest material should be used in outdoor situations. Very thin cuttings have low food reserves and may deteriorate before rooting. If conditions are unsuitable for lining out, cuttings can be bundled, labelled and heeled in. Sharp sand or recycled growing media can be used for heeling in and the cuttings inserted in trenches to about half their length. Labels should be clearly visible and different species well separated.

Some cuttings may begin to form callus tissue and initiate roots prior to lining out, which should be done promptly in spring as soon as soil and weather conditions are suitable, inserting the cuttings to about half to two-thirds of their length, 15–20 cm apart in the rows. Cuttings should be firmed in well. On heavy soils, raised beds offer the advantage of improved drainage.

With this system, the cuttings usually remain in situ until the autumn, when they are lifted for growing on, either in the field or in containers. During this period, good weed control and adequate summer irrigation are essential requirements to produce quality liners.

Heated bins

This technique was developed at NIAB EMR for the improved rooting of leafless winter cuttings (hardwood cuttings) and is suitable for a range of HNS subjects including *Acer campestre, Acer platanoides* 'Crimson King', *Acer rubrum, Laburnum, Platanus x hispanica, Sorbus intermedia, Tilia, Ulmus glabra* and various clonal rootstocks of *Malus* and *Prunus*. Timing, hormone preparation and base temperature are crucial to success.

The bins should be constructed in a cool, insulated building to maintain dormancy and restrict bud development. They need not be of any fixed size but are typically some 1.2 m square and 1 m high, such that they can accommodate lengthy cuttings. A bin of this size will hold around 5,000 cuttings. Insulating blocks are used for the construction to retain heat in the rooting area and the propagation medium must be well drained for successful callusing and root initiation of the cuttings; floor blocks must, therefore, have drainage gaps between them.

Once the blocks are in place, heating cables or a suitable heat foil are laid on the floor of the bin to provide the necessary base heat; accurate heat control using reliable temperature probes is essential.

A weld-mesh screen is placed over the cables for protection. Finally, the rooting medium is placed in the bin; mixes of peat with perlite or bark work well.

Usually, one-year vigorous healthy shoots are used for cuttings, ideally taken from clonal stock hedges or mother plants. Pencil thick shoots removed close to the previous year's wood to include the swollen shoot base are ideal.

Cuttings root most readily when taken during October and early November in the case of plum rootstocks, ornamental *Prunus* and *Tilia* species, and between mid-February and March. Autumn cuttings must have any foliage removed and those taken in spring should be collected before they come into leaf, so that the food reserves of the cutting can be channelled into rooting.

A 'quick dip' hormone treatment of IBA is normally used, except where preformed roots are present, for example, with the cherry rootstock 'Colt', in which case it is unnecessary. For uniform rooting, all cuttings should be dipped to the same depth and for the same duration.

The optimum temperature for base heat is around 21°C for two or three weeks. All cuttings should be placed at the same depth in the heated bin, usually around 2.5 cm above the heat source.

The cuttings should be checked regularly for any watering need to ensure the rooting medium is adequately moist. Once root initiation has occurred, the base temperature can be gradually reduced before being switched off in readiness for lining out. The aerial environment should remain cool and well vented to discourage shoots from breaking into early leaf, as this will hinder root development and post-planting establishment.

Heated bins are used to initiate callus and roots quickly

The cuttings can be lifted from the bin as soon as conditions are suitable for lining out or, if more convenient, they can be bagged and cold stored until required. Well-grown hardwood cuttings of rootstocks can be budded during the summer or grown on for a full season before being grafted or budded the following year.

Good bin hygiene is important and the rooting medium should be changed each year, otherwise its structure will deteriorate and drainage will suffer and disease infection may ensue. Bins should be disinfected before re-use.

Direct sticking of cuttings

Direct sticking may be defined as the insertion of an unrooted cutting or cuttings into an individual receptacle, which may be a liner pot, intermediate pot or final pot.

By blending pine bark with different grades of peat, to which controlled release fertiliser is added, a rooting medium with a suitably high air filled porosity for quick rooting can be obtained and good nutritional status achieved, serving as both a rooting and growing medium for the plants.

Advantages and disadvantages of direct sticking

The principal advantages of direct sticking are reduced root disturbance (leading to better plant establishment) and quicker, better quality plants. Disadvantages include the greater inputs required at propagation, notably of labour, space, materials (pots, media, etc.) and propagation material (when multi-sticking). When carried out correctly, direct sticking can save a lot of time and handling.

It is not a new technique but improved methods of propagation, notably the successful blending of pine bark with peat and controlled release fertiliser, enable it to be used more widely, with scope for significant reductions in production times of easy rooting subjects. With this development, one of the main obstacles to successful direct sticking was overcome, namely the need to begin feeding during and immediately after rooting.

Its success depends on:

- Using easy rooting subjects (greater than 75% take)
- Good, well-structured rooting media with adequate nutrition
- Adequate available propagation space when required
- Sufficient and timely quantities of uniform, good quality cutting material
- Care in spacing plants to maintain quality

Research undertaken

Work at HRI Efford considered the responses of a range of HNS subjects to direct sticking, both under mist (summer) and polythene covers (autumn and winter), with a principal aim being to establish whether a propagation mix containing higher levels of fertiliser could be used without adversely affecting rooting. Under both environments, the cutting quality and early growth of direct stuck material (into 7 cm pots) were better than that of tray rooted cuttings, where competition for available nutrients was greater.

Overall, results were also better in a 50:50 peat and pine bark mix than a peat and grit one and cutting quality of both vigorous and some salt sensitive evergreen species under mist improved with increasing fertiliser incorporation (up to 2 kg/m^3 12–14 month controlled release fertiliser). Leaf colour was improved, stem thickness was greater, and leader and axillary buds were more active, producing well-rooted small liners direct from propagation. No problems were encountered with the 2 kg/m^3 rate of fertiliser in the peat and bark mix but rooting of *Camellia* was reduced where it was used in the peat and grit mixes.

Under polythene, cuttings did less well in fertilised peat and grit mixes, particularly at the higher rate of fertiliser (2 kg/m^3). While the inclusion of bark improved rooting, the type and rate of controlled release fertiliser was significant, as, under this system, too high a rate of 12–14 month fertiliser (2 kg/m^3) was damaging to sensitive species (Japanese *Azalea*); the same rate of a 16–18 month formulation (with a slower pattern of nutrient release) proved safer.

Ultimately, the choice of controlled release fertiliser (particularly the rate) will depend upon:

- Whether bark is used and to what extent
- The length of time cuttings require to root well
- Whether or not base heat is used
- The rooting environment (polythene, mist or fog)
- The season during which propagation takes place
- The plant species concerned

Usually, a 12–14 month product will suffice, although 16–18 month formulations are safer for salt sensitive subjects, especially where base heat is used under polythene. 1 kg lower rates (1 kg/m^3) are usually required for autumn and winter propagation, particularly under polythene and where base heat is used.

Work at HRI Efford concluded that, to obtain the most benefit from this approach to propagation, the timing of subsequent potting on is important; the earlier the potting of slow growing species or those with distinct growth flushes, the better by the end of the season. In trials, a delay in potting of the more vigorous subjects was less detrimental as their growth rate enabled them to catch up on the earlier potting.

The poor use of space resulting from cutting failures when direct sticking can be offset by using more cuttings per pot. However, an adequate stock plant area is required, as are correct pruning schedules, to produce timely supplies of a greater number of uniform cuttings.

HNS subjects suitable for direct sticking

Subjects propagated successfully at HRI Efford by multi-sticking cuttings into 7 cm pots included various ground cover subjects (including *Hebe, Hedera* and *Hypericum*), easy rooting amenity subjects (such as *Forsythia*, *Senecio* and *Weigela*), hedging species (*Griselinea* and *Ligustrum*), higher value subjects (evergreen *Azalea*, *Camellia* and *Pittosporum*) and even some slower rooting and growing subjects (*Elaeagnus pungens* 'Maculata'). While three cuttings per pot can produce excellent results, for many easy rooting, vigorous species, two cuttings usually suffice.

Popular evergreens such as *Hedera, Prunus tricolor* and evergreen *Prunus* species can also be direct stuck into liners, 1, 2 or 3 litre pots and rooted without heat under polythene during the late summer and autumn period, while *Choisya, Escallonia, Hypericum, Lavandula, Pyracantha* and *Potentilla* can be direct stuck successfully into 1 or 1.5-litre pots during the summer.

A wide range of HNS can be propagated economically by direct sticking, including evergreen *Prunus*

Easy rooting deciduous subjects like *Buddleia, Hypericum, Philadelphus, Potentilla* and *Weigela* also root well when direct stuck into 1 litre pots in summer under mist or shaded plastic. *Buddleia* will in fact direct stick successfully into 3-litre pots in summer to produce good quality saleable plants the following spring, while cultivars of *Cornus alba* also root readily but may require a little longer to produce saleable plants.

Crop protection

The high humidity environments created for seed germination and the rooting of cuttings also provide ideal conditions for pests and particularly diseases. Notable examples include: *Botrytis*, *Phytophthora, Pythium* and *Rhizoctonia,* the latter three being commonly associated with 'damping-off' symptoms in seedlings and cuttings. Pests such as aphids can also be quite common on leafy cuttings, while sciarid fly larvae can feed and damage young roots and stem bases.

Sciarid fly larvae damage young roots and stem bases

Contaminated stock plants or nursery crops from which propagation material has been taken are a common source of problems, underlining the importance of disciplined nursery hygiene, routine pest and disease monitoring and clean stock. Careful watering and environmental control are also important, particularly in respect of humidity under polythene, mist and fog.

As seedlings, cuttings and liners are usually quite soft and juvenile when in active growth they are susceptible to problems and more likely to sustain damage as a result of pesticide application, especially under mist or fog.

There is also a diminishing range of suitable products approved for use under protection (although some of the newer biopesticides have potential). As such, biological pest control agents deployed within integrated pest management programmes are a safer, more sustainable and often more effective form of pest control. Recent moves towards integrated crop management seek to build on this and bring together the use of biological control agents with good cultural practice.

Integrated pest management (IPM)

IPM combines biological and cultural control measures for crop protection with the minimum use of compatible pesticides. Used correctly, it is a safer, more effective and environmentally responsible approach that reduces the use of and reliance on chemicals so helping to reduce the development of pesticide resistance.

Cultural measures include good nursery hygiene, use of clean stock and routine crop monitoring.

An increasing number of HNS growers, including propagators, now use IPM under protection to control a range of pest problems, including aphid, sciarid fly larvae, glasshouse whitefly, two-spotted spider mite, thrips and vine weevil larvae. These protected environments lend themselves well to the use of biological control agents, which, when coupled with accurate and regular pest monitoring, can be very effective. Reduced reliance on broad spectrum pesticides also enables more naturally occurring beneficial species to establish, some of which overwinter naturally under protection or move inside from outdoors in spring to provide additional control.

For successful programmes, trained staff should monitor crops weekly using sticky traps, indicator crops and pheromone traps as appropriate. A good quality x10 magnification hand lens should be used when checking for pests and biological control agents.

The AHDB Horticulture ***HNS Crop Walkers' Guide*** covers major pests, diseases, biological control agents (and beneficials) and nutritional, cultural and physiological disorders and is a useful source of reference.

Using IPM in propagation situations

Biological pest control is well suited to propagation and liner production, where leaf canopies frequently touch, so facilitating the rapid spread and establishment of predators, normally introduced in a bran or vermiculite carrier from a release tub. However, the higher temperature and closer humidity environments of propagation units, may restrict the range of biological pest control agents and release methods that can be used.

The predatory mite *Phytoseiulus persimilis* commonly used to control two-spotted spider mite is less effective at higher temperatures (above 25°C) and so a different, more temperature tolerant predatory mite, *Neoseiulus (Amblyseius) californicus*, may be more suitable in propagation purposes.

Slow release sachets used for the introduction of some biological control agents (such as *Amblyseius andersoni* for two-spotted spider mite control) are unsuitable for use in damp propagation environments. Extra care is also required to ensure release bottles of parasitic wasps placed in propagation areas are not left upright, where they can fill with water and so drown the biological control agents inside.

A further consideration in propagation areas is the usually rapid throughput of crops, which will necessitate more frequent introductions of biological control agents. Sticky traps used to monitor flying pests such as whiteflies and sciarid flies may also require more frequent changing when used in propagation environments due to the higher number of flies often associated with higher temperatures and very close, humid environments.

Integrated crop management

Integrated crop management is a sustainable approach to growing, which builds on and includes IPM. In effect, it is a broader concept that brings together the correct identification of crop problems through monitoring and staff training, with cultural control measures (nursery hygiene, careful water management and accurate environmental control), biological control products, biopesticides and the use of compatible pesticides to control pests, diseases and weeds.

Like integrated pest management, when undertaken correctly, integrated crop management combines high levels of sustainable crop protection with enhanced plant quality, mitigating pesticide resistance issues while providing a high degree of crop safety. It is also more socially acceptable than the repeated use of synthetic pesticides, particularly the use of broad spectrum, persistent products.

AHDB Horticulture project HNS 185: ***Understanding and managing crop protection through integrated crop management**,* aimed to assess and quantify the present level of adoption of the management technique in nursery stock. The results will enable better practice methods to be identified and developed, which are economically viable, practical for growers to implement and take account of ongoing changes in crop protection legislation, notably the EC Sustainable Use Directive (SUD), which requires growers to reduce the use of pesticides and demonstrate good practice by 2014.

Biopesticides and compost teas

Biopesticides link well with the broader concept of integrated crop management and are based on beneficial microorganisms or other biologically based active ingredients.

Current commercial products include Serenade ASO (based on the bacterium *Bacillus subtilis*), Prestop (based on the fungus *Gliocladium catenulatum),* T-34 (based on the fungus *Trichoderma asperellum* T-34) all with activity against diseases and Met-52 (based on the entomogenous fungus *Metarhizium anisopliae*), used for protection against vine weevil. Other examples include Naturalis-L, developed using the entomopathogenic fungus *Beauveria bassiana* for the control of leaf pests (notably, aphids and whitefly) and Dipel DF, a bacterial insecticide based on *Bacillus thuringiensis* a naturally occurring bacterial pathogen of caterpillars.

There is continuing interest in the potential of compost teas to stimulate healthy crop growth and reduce the incidence and severity of diseases such as *Botrytis*, downy mildew, leafspots and various soil and water-borne infections. Their beneficial effect depends on the live microorganisms they contain acting as biological control agents. Given they are also safe to crops and are user-friendly, their appeal is understandable yet commercial experience has been variable in terms of disease control.

AHDB Horticulture project HNS 125: ***Hardy Ornamentals: the potential of compost teas for improving crop health and growth**,* sought to evaluate the preparation, application and effects of compost teas on UK commercial nurseries and provide growers with practical information to improve their use. Overall, the results were variable and inconclusive. However, where compost teas have been successfully integrated within commercial crop management programmes, significant cost savings have accrued due to more limited use of fungicides and fertilisers.

Based on present knowledge, compost teas are likely to be most effective when used as part of a wider, integrated crop management approach. Growers do, though, need to experiment, refine and adapt compost teas to their own situation and range of crops.

Other products

As well as biopesticides and micro-feeding with compost teas, other products are available commercially that claim to improve plant resistance to pests and diseases. They are usually based on nutritional elements, micronutrients, repellents, beneficial microbes or plant extracts and are thought to improve plant resistance by either creating a microbial balance in favour of beneficial microorganisms, which act as disease antagonists, inhibiting the formation and germination of disease spores or by acting as a plant wash, feed supplement, plant 'enhancer' or 'tonic'. Not all of these products have been officially registered and, therefore, their use cannot be recommended.

Pest and disease control

Common pest problems in propagation

Aphids

Several aphid species are common on protected ornamentals including propagation and liner crops, most notably peach-potato aphid (*Myzus persicae*), potato aphid (*Macrosiphum euphorbiae*), melon and cotton aphid (*Aphis gossypii*) and glasshouse and potato aphid (*Aulacorthum solani*). They feed on and damage a wide range of subjects, causing leaf yellowing and distortion, producing sticky honeydew that leads to the development of sooty mould. Aphids are easily transferred on tip cuttings and soft, sappy propagation material. They may also act as virus vectors and infected material should not be used for propagation.

Various biological control agents are now available for safe and effective control, mainly parasitic wasps such as *Aphidius colemani* and *A. ervi.* Products are also available that combine several species of parasitic wasps in one tube, making control of mixed aphid species easier and more reliable. The predatory midge, *Aphidoletes aphidimyza* and the green lacewing *Chrysoperla carnea* are useful supplements to deal with aphid 'hot-spots'.

Sciarid and shore flies

Sciarid fly larvae (*Bradysia difformis*) are a common pest of HNS seedlings and cuttings, especially slow rooting species, feeding in and around the growing media on fungi, young roots and stem bases. They thrive in damp, humid conditions, hence their occurrence on

Case study 6: Walberton Nursery

An integrated approach to crop protection

Sussex-based Walberton Nursery grows around one million shrubs and herbaceous perennials each year for sale in 1, 2 and 3-litre pots to garden centres. Around half of these are propagated in-house and the remainder bought in as rooted plugs or pot liners.

Low polythene tunnels (clad with XL Thermo-prop film) over a heated concrete floor (minimum 20°C) are used to root and wean a wide range of cuttings, including *Crinodendron, Erysimum, Lavandula, Penstemon, Photinia and Spiraea.*

"We place a strong emphasis on managing the propagation environment well, particularly humidity levels throughout the rooting process," explains Technical Manager David Hide. "To increase levels, we may place trays onto capillary matting and then cover with polythene and, in some instances as we begin to wean, we may place fleece underneath the polythene cover prior to removing it.

"We also vary the environment according to the subjects involved, for example, we like to keep *Lavandula* drier while *Spiraea* prefer a wetter regime," says David. "We vent quite freely too during hot weather, so the cuttings remain relatively cool.

"We propagate cuttings throughout the year and, for the most part, use milky polythene covers over the tunnels but prefer a clear film in winter so the cuttings receive as much light as possible. Ventilation, heating and shade screens in the glasshouse are all controlled automatically.

"We are also keen on good hygiene and diligent crop protection," continues David. "We have a routine fungicide programme, which includes the biopesticide Serenade ASO to control *Botrytis*, which is our principal concern, especially with micropropagated material. We also like to crop walk weekly to check pest levels. Stock plant and propagation check-sheets are used too, for monitoring the quality, and pest and disease status of all cutting material, including that which is bought in; we feel this helps drive up the quality of material coming into the propagation unit and we have developed benchmarks as part of a wider appraisal system.

"We remove nursery waste promptly, disinfect floor areas, use only fresh propagation media and change the propagation films regularly. The condition of the cuttings in the trays is also checked regularly so that anything that's damaged or diseased can be spotted and dealt with promptly before it becomes a bigger problem.

"We like to use biological pest control where we can and use the predatory rove beetle *Atheta* (via breeder boxes) for sciarid fly control and the predatory mite *Neoseiulus (Amblyseius) cucumeris* for thrips control (plugs are 'loaded up' with predators before moving them onto the nursery) as we feel these are much more effective and safer to crops, especially cuttings, than insecticides.

"We may also look at *Amblyseius andersoni, Neoseiulus (Amblyseius) californicus* and *Phytoseiulus persimilis* for two-spotted spider mite control, for the same reasons; if used correctly, they are usually more effective and a good deal safer than chemical control, especially in propagation situations. We also make fortnightly applications of the biopesticide Naturalis-L during the summer for general control of leaf pests."

Neoseiulus (Amblyseius) cucumeris

The nursery is geared to integrated crop management and uses biological pest control to good effect. "We've found the development work on Atheta breeding programmes very useful as sciarid can be a particular problem in propagation and the predators give us effective control. The follow-on AHDB Horticulture factsheet 06/10 is especially useful to us as we make good use of breeder boxes in the propagation unit. We may also look at *Atheta* and the predatory flower bug *Orius* as a supplement to *Amblyseius* predators for thrips control under protection," says David.

The nursery has also experimented with compost tea as an aid to improving crop health and growth in propagation and liner crops but didn't see any noticeable differences between treated and untreated crops, so discontinued it. "We were converts to compost tea," says David, "but stopped when we couldn't see what we were achieving. We applied compost tea to a number of batches of plants and left similar sized batches untreated and could not see any difference and so gave up on all the additional work", he concludes.

crops in propagation and can create serious damage if not controlled. The larvae are around 5–8 mm long, off-white in colour with a black head and no legs. The most frequent sign of attack is wilting, poor growth and collapse of affected plant material.

The adults are small (3–4 mm long) grey-black gnat-like flies with long legs and antennae. They are commonly seen either walking or hovering over the surface of the growing medium, particularly when it is damp or overly wet. They do not feed on plants but can act as vectors of disease pathogens, notably *Pythium*. Their presence in large numbers can also pose a nuisance to nursery staff working nearby.

Sciarid fly larva

Sciarid flies are often mistaken for shore flies (*Scatella tenuicosta*) but the latter are larger, stouter and more fly-like. Like sciarid fly adults, shore fly adults do not harm plants but feed on algae, hence, they can be present in large numbers where excess moisture has enabled algae to develop. As such, propagation areas are ideal breeding grounds and their large-scale presence can also be a nuisance to nursery staff. They are often seen sitting on plant foliage or the surface of the propagation medium and fly upwards when disturbed.

Sciarid fly adult

Both pests can be reduced by good nursery hygiene and avoiding excessive moisture. Prompt removal of plant debris and the use of yellow sticky traps for monitoring will also reduce numbers.

While a number of products are currently available for the chemical control of both pests (adults and larvae), a more effective and sustainable approach for sciarid control is to use biological control, for which species of the predatory mites *Hypoaspis* and *Macrocheles* and the predatory rove beetle *Atheta coriaria* are available.

The predatory mite *Hypoaspis* can provide effective control of sciarid fly larvae

Atheta coriaria can be used against both sciarid and shore flies and may contribute to the biological control of the ground dwelling stages of western flower thrips too. The black adult beetles are quite large (around 5 mm long) and fly readily; both adults and larvae are voracious predators. This predator appears to survive better than *Hypoaspis* in high moisture situations and so may be more suitable for use in propagation unit environments.

Most recently, commercial success has been achieved using ‘breeder boxes’ for *Atheta.* These were developed through AHDB Horticulture projects PC 239 and PC 239a: ***Protected herbs, ornamentals and celery: Development of an on-nursery rearing system for Atheta coriaria for reduced cost biological control of sciarid and shore flies,*** and are simple polystyrene boxes with holes drilled in the sides and top, containing moist peat and a food source. When *Atheta* is released into the boxes, they breed rapidly and fly out to colonise other areas.

The predatory rove beetle *Atheta coriaria* can also be used for safe and effective control of sciarid fly larvae

AHDB Horticulture factsheet 06/10: ***Grower system for rearing the predatory beetle Atheta coriaria,*** provides more detailed guidance on the use of breeder boxes for reduced cost biological control of sciarid and shore flies.

Both *Atheta* and *Hypoaspis* require a minimum temperature of 12–15°C to be effective and so should not be used in unheated crops over winter.

Biological control of sciarid fly larvae can also be achieved using the insect pathogenic nematode *Steinernema feltiae* applied as a growing media drench. Usually, a minimum temperature of 10–14°C is required for effective control, depending on the product.

AHDB Horticulture factsheet 08/02: ***Control of sciarid flies in protected ornamentals,*** provides more advice on dealing with sciarid flies under protection.

Slugs and snails

Slugs and snails favour damp, humid conditions and can create serious damage among young seedlings and cuttings, holing out and quickly shredding young foliage and consuming growing points. In recent years, the water snail species *Oxyloma pfeifferi* (small, pale brown or black in colour up to 12 mm long) has become very common in nursery stock, feeding on a range of plants, algae and decaying vegetation. *Choisya, Cordyline* and *Phormium* appear especially vulnerable to attack.

Several slug species can be found in protected ornamentals, the most common being *Deroceras panormitanum*, which is brownish-grey and up to 35 mm long. Many HNS subjects are frequently attacked including *Choisya, Clematis, Cordyline, Magnolia, Phormium* and various herbaceous perennials, notably *Hosta* and *Ligularia*. Damage is very visible and can occur quickly when numbers build up; seedlings, cuttings, liners and overwintered herbaceous crops can be especially vulnerable.

Water snails favour warm, damp conditions and are a common problem in propagation crops

Cultural control measures are the key to successful control of both pests, including careful water and environmental management to avoid overly wet conditions, good bed drainage and rigorous nursery hygiene to reduce their numbers.

AHDB Horticulture project HNS 105/105b: ***Integrated control of snails and slugs,*** highlighted the potential of permeable ground cover fabrics impregnated with a latex-based copper hydroxide treatment for discouraging slugs and snails and these may be useful for propagation beds, as they also help to control rooting through. Biological control using the mollusc pathogenic nematode *Phasmarhabditis hermaphrodita* (available commercially as ‘Nemaslug’) can also provide some control during the spring and autumn months.

AHDB Horticulture factsheet 07/02: ***Integrated control of snails and slugs*** and AHDB factsheet: ***Integrated slug control,*** provides a more detailed overview of control measures for both pests.

Thrips

They are an increasingly common and serious leaf pest of protected nursery stock, including propagation and liner crops, where feeding damage causes an unsightly and damaging white flecking and growth distortion. The main species causing damage on HNS is the western flower thrips, which can also transmit damaging viruses to ornamental crops. Common host crops include: *Campsis, Chaenomeles, Choisya*, *Clematis, Lavatera, Passiflora, Photinia* and various herbaceous crops, including *Cosmos* and *Crocosmia*.

Western flower thrips larvae and adults, a common and serious pest of an increasingly wide range of HNS

Routine monitoring using indicator crops and blue sticky traps enable rapid detection and prompt control.

Chemical control is difficult and complicated by widespread resistance among thrips populations. As such, biological control using the predatory mites *Neoseiulus (Amblyseius) cucumeris* and, more recently, *Amblyseius swirskii or Amblyseius montdorensis* has become the principal means of control under protection and the most effective when used correctly. These mites can be used in propagation areas and among liner crops. Ground dwelling *Hypoaspis* and *Atheta* predators, used for sciarid fly larvae control, also feed on thrips larvae and pupae in the growing medium or on floor or bench coverings and so are a useful supplement to *Amblyseius*.

The predatory flower bug *Orius* is also a useful supplement to *Amblysieus* mites; it is very active and feeds on a range of prey including thrips but tends to fly elsewhere if food sources are scarce.

AHDB Horticulture factsheet 14/09: ***Thrips control on protected ornamental crops,*** provides more detailed guidance on dealing with thrips.

Two-spotted spider mite

This is a frequent and troublesome leaf pest of a wide range of HNS subjects, notably *Buddleia, Ceanothus, Choisya, Cordyline, Crinodendron, Euonymus, Exochorda, Hydrangea, Magnolia, Phormium, Potentilla, Skimmia, Wisteria* and various alpines, herbaceous perennials and grasses. While disliking humidity and so less frequent in propagation environments, it does favour higher temperatures and is commonly found on container-grown stock plants, weaned material, rooted plugs and liners grown on under protection. Damage symptoms, typically include, a yellowing and bronzing of the foliage, leaf speckling and a gradual loss of plant vigour. With heavy infestations, webbing quickly occurs, making plants unsaleable.

Two-spotted spider mite is a frequent leaf pest of HNS

Chemical controls are widely used but resistance is widespread leading to variable levels of control. In propagation situations, spray scorch of soft, young growth is a further consideration. Biological control agents are now widely used for successful control, mainly the predatory mite *Phytoseiulus persimilis* although this has some limitations, mainly its dislike of temperatures over 25°C, sensitivity to pesticide residues and reliance on two-spotted spider mite as a food source. For these reasons, there is now more use of other predators, usually to complement *Phytoseiulus* rather than replace it, notably *Neoseiulus (Amblyseius) californicus* and *Amblysieus andersoni*, both of which are more tolerant of higher and lower temperatures and can survive on other food sources in the absence of two-spotted spider mites. Larvae of the midge *Feltiella acarisuga* can also be an effective predator of two-spotted spider mites.

Currently, use of *Neoseiulus (Amblyseius) californicus* is only permitted in glasshouses and fully enclosed polythene tunnels; the introduction rate is also governed by its release license. The native species *A. andersoni* can be used without such restrictions on outdoor nursery stock, so it may have a useful role to play in stock plant areas during the spring and summer period.

AHDB Horticulture factsheets 08/05: ***The biology and control of two-spotted spider mite in nursery stock***, and 12/09: ***Biology and control of mites in pot and bedding plants,*** provide further guidance.

Vine weevil

The black vine weevil (*Otiorhynchus sulcatus*) is one of the most damaging and difficult to control pests of nursery stock, including rooted cuttings and pot liners, from where it can readily transfer to larger, saleable stock when potted on. The wider use of peat alternatives, notably coir fibre, bark and wood-fibre also appears to favour vine weevil, underlining the need for effective crop protection. Key hosts include *Azalea, Cornus, Cotoneaster, Fuchsia, Euonymus, Parthenocissus, Pyracantha, Rhododendron, Taxus* and *Viburnum*. Various alpines and herbaceous perennials are also susceptible, notably*, Astilbe, Bergenia, Epimedium*, *Heuchera, Hosta, Primula, Saxifrage* and *Sedum*.

The adult is a large black weevil with small yellow-brown patches on its back. It cannot fly but is an active climber. Usually, it hides during the day among plant debris, leaf litter or under pots and trays and feeds at night, causing an unsightly marginal leaf notching. The creamy white larvae with brown heads usually hatch and feed on the root systems of plants between July and the following spring, damaging bulbs and corms, root systems, and stem bases, leading to stunted growth, wilting and collapse of plants. Larvae pupate in the growing medium in late spring and new adults normally emerge from May onwards, although this may be earlier under protection.

Vine weevil larvae can seriously damage rooted cuttings, plug plants and liners

The cultural control measures used against vine weevil are especially important, notably good nursery hygiene and clean stock. Check bought-in plugs and liners as a matter of routine and isolate these from other nursery crops until checked.

In propagation situations, biological control using insect pathogenic nematodes are crop safe and especially useful; used correctly, they can provide effective control of young vine weevil larvae.

Most recently, research (AHDB Horticulture project HNS 133: ***Development of the entomogenous fungus Metarhizium anisopliae for control of vine weevil and thrips in horticultural growing media***), highlighted the potential of the entomogenous fungus *Metarhizium anisopliae* for biological control of the larvae in growing media, particularly when used alongside cold tolerant entomopathogenic nematode products. It has since been developed commercially, as a granular biopesticide product (Met-52) for incorporation into growing media at all production stages including propagation.

AHDB Horticulture factsheet 24/16: ***Vine weevil control in hardy nursery stock*** provides further guidance on vine weevil control and the range of susceptible plant host species.

Whiteflies

Both the glasshouse whitefly (*Trialeurodes vaporariorum*) and the notifiable tobacco whitefly (*Bemisia tabaci*) are common leaf pests of protected crops and can easily transfer to propagation environments on contaminated cuttings, including bought-in plant material, so vigilance and routine quality control checks are important. Leaf discoloration due to feeding activity is a common symptom but heavily infested plants become sticky with honeydew and unsightly with sooty moulds. Key host crops include: *Abutilon, Arbutus, Campsis, Ceanothus, Clematis, Cotinus, Hebe, Jasminum, Lavatera, Lonicera, Melianthus, Penstemon, Philadelphus* and *Viburnum*.

Whiteflies can cause serious leaf damage on a range of crops

Yellow sticky traps, checked weekly and changed monthly are an essential aid to whitefly monitoring. The parasitic wasp *Encarsia formosa* is a widely used and effective biological control agent when correctly used (although it is more effective against glasshouse whitefly). *Eretmocerus eremicus* is another parasitic wasp that can be considered and is active against both glasshouse and tobacco whitefly. It also appears to tolerate higher temperatures and is more resistant to pesticide residues than *Encarsia*. The predatory ladybird *Delphastus catalinae* is a useful supplement too, for controlling whitefly 'hot spots' (although it should only be used when temperatures are 21°C or higher with good natural light levels).

Common disease problems in propagation

Botrytis

Botrytis or 'grey mould' is a common problem in propagation and liner situations, favoured by damp, high humidity environments and exacerbated by senescing and decaying plant tissue. Clean propagation material and good cultural practice is therefore crucial in avoiding and controlling this disease, which often begins as a secondary infection colonising dead material before spreading to healthy foliage as a primary disease. The disease leads to characteristic pale brown tissue decay and fluffy fungal strands bearing grey-brown spore clusters.

Botrytis is favoured by high humidity propagation environments

Propagation material should be checked daily and picked over promptly to remove any decaying plant material.

AHDB Horticulture factsheets 23/02: ***Control of grey mould (Botrytis cinerea) in container-grown ornamentals: unheated greenhouse crops***, 24/02: ***Control of grey mould in container-grown ornamentals: heated glasshouse crops*** and 25/02: ***Controlling humidity to minimise the incidence of grey mould (Botrytis cinerea) in container-grown ornamentals: heated glasshouse crops***, provide further guidance on dealing with *Botrytis* in protected crops.

Damping-off

Damping-off requires the same diligent approach to nursery hygiene and crop husbandry as when dealing with *Botrytis*. Clean trays, good drainage of beds and propagation media and periodic disinfection of materials are especially important, linked as the disease often is to the fungal pathogens *Pythium* and *Phytophthora*, which favour damp conditions and high moisture levels. *Rhizoctonia* infection also creates damping-off symptoms but is more usually associated with drier environments.

Fungicides are available to protect against damping-off, usually applied as growing media drench treatments following seed sowing or insertion of cuttings but such products need to be harnessed with good cultural practice for effective, lasting control.

There is also interest in the wider use of various microbial products to aid control, either incorporated into the growing medium or, applied as drench treatments, as protectants, although commercial experience to date appears variable and further work is required to fully evaluate their role.

AHDB Horticulture factsheets 16/04: ***Control of Phytophthora, Pythium and Rhizoctonia in container-grown hardy ornamentals*** and 17/04: ***Control of Pythium, Phytophthora and Rhizoctonia in pot and bedding plants***, provide more detailed guidance on the control of damping-off disease pathogens.

Weed control

Weed control in container-grown protected crops

Weed contamination from stock plants including seed on cutting material or root fragments of perennial weeds on field-grown herbaceous stock, can be problematic. Chemical weed control is often difficult in propagation and protected environments due to the enhanced risk of damage because of the greater softness and sensitivity of the plant material and the lack of suitable herbicide products that are safe and approved for use in such situations. Weaned cuttings and pot liners with shallow, limited root systems are also more susceptible to residual herbicide damage or growth suppression.

Nursery hygiene

Given the complications of chemical control under protection, good nursery hygiene is particularly important and should form the cornerstone of all weed control strategies. Principal weed sources include non-crop areas such as pathways, bed edges and areas between tunnels and glasshouses as well as rubbish heaps, uncovered waste skips, used pots and old, unsold stock.

Good nursery hygiene is crucial for safe and effective weed control

Routine nursery hygiene measures to minimise weed contamination should include:

- Covering waste heaps
- Covering growing media storage areas and water storage tanks
- Controlling background weeds (on paths, headlands and reservoir banks)
- Using clean pots and trays
- Disinfection of beds and benches and regular changing of bed covering materials and capillary matting before they become too soiled
- Monitoring crops regularly and hand weeding promptly

AHDB Horticulture factsheets 03/14: ***Use of chemical disinfectants in protected ornamentals production*** and 10/07: ***Guidelines on nursery hygiene for outdoor and protected ornamental crops****,* provide more detailed guidance.

Cultural control measures

Cultural weed control combines good nursery hygiene with diligent crop husbandry, notably the management of water, crop nutrition and the crop environment. In propagation and liner situations, careful water management to minimise weeds such as moss and liverwort is especially important. Other cultural control measures of particular relevance to propagation and protected crops include:

- Ensuring weeds are well-controlled in stock plant areas
- Only taking cuttings from clean, weed-free nursery crops
- Ensuring bought-in cutting material, modular raised plants and liners are clean and weed-free
- Rigorous control of weeds in and around propagation beds and pathways
- Well-targeted hand weeding to ensure prompt removal of weeds in propagation areas before they flower
- Prompt and careful removal of weeds, including moss and liverwort from modules when potting on.

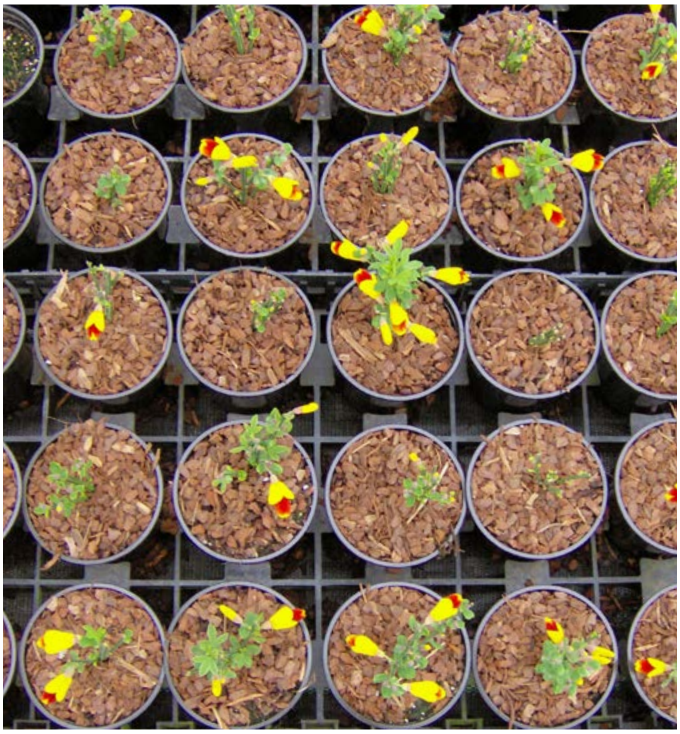
Guidance on the practical aspects of handling bought-in plant material can be found in AHDB Horticulture factsheet 06/08: ***A guide to best practice when handling bought-in plants***.

AHDB Horticulture project HNS 93: ***Nursery stock propagation: moss, liverwort and slime control****,* considered weed control in rooted plugs and pot liners under protection, given that moss and liverwort in particular are serious problems when holding back rooted plugs pre-potting and during young plant development following liner potting. With plugs in particular, difficulties in achieving uniformity of watering and the presence of empty cells from cutting failure, accelerates the colonisation of growing media surfaces by moss and liverwort. These are difficult to completely hand weed before potting; some debris and inoculum inevitably transfer to the liner, where they quickly re-establish, especially with overhead irrigation and in overwintered crops.

The principal finding of HNS 93 and, subsequently, of HNS 93c: *Protected container-grown nursery stock: chemical and non-chemical screening for moss and liverwort control in liners*, was that the adoption and management of drier watering regimes or use of reduced peat growing media markedly reduced moss and liverwort problems and was an effective means of cultural control.

Mulches, pot-toppers, tray mats and bed covering materials

Loose-fill mulches, pot-toppers and permeable bed covers all help to exclude light and reduce surface moisture, so helping to control weeds. Mulches are capable of providing good levels of safe weed control in short-term container-grown plants and are a useful option for herbicide sensitive crops such as weaned cuttings and stock plants. They are especially effective at combating moss and liverwort. Various bark-topping machines are now available commercially to apply mulches and so ease and speed their application.



Loose-fill mulches such as bark offer a safe alternative to chemical weed control

In HNS 93c, pine bark applied to a depth of 10 mm was partially effective as a mulch, delaying the onset of moss and liverwort growth. This approach is now more widely used, combining as it does safe and reasonably effective control of these weeds with an attractive visual appearance.

Pot-toppers are permeable discs or mats that are placed over the surface of the growing medium to control weeds. They are usually applied once, after potting, and, for best results to a clean, weed-free surface. In propagation situations, they are a useful option for safe and effective weed control and can be considered for pot liners although their application to small pots is time-consuming and, hence, quite costly. Several products are now commercially available to fit a range of pot sizes, including those made from sustainable sources such as hemp. A further and more recent development from the Netherlands is the use of permeable tray mats, which act as a mulch to control weeds in plugs transplanted into trays under protection.

Permeable tray mats control weeds safely in transplanted plugs

Growing media amendments

Commercial experience and research indicates that weeds such as moss, liverwort and pearlwort are less of a problem where bark and wood-fibre are used in the growing medium and the percentage of peat is reduced to 50% by volume.

HNS 93c also considered the potential role of growing media amendments to reduce industry reliance on chemicals for reducing moss and liverwort problems in liners alongside a range of herbicide programmes. The incorporation of 30% wood-fibre in a peat-based medium substantially reduced moss and liverwort incidence making chemical control much easier.

In more recent work (AHDB Horticulture projects HNS 126: ***Biology, epidemiology and control of liverwort infestation in nursery plant containers****,* and HNS 175: ***Liverwort control using novel techniques***), various oilseed meals including *Limnanthes alba, Sinapis alba* and oilseed rape (each of which contain various glucosinolates that break down to form bioactive secondary products) have been shown to provide some control of liverwort when used as a mulch.

With good nursery practice and non-chemical alternatives, there should be no need to use or consider herbicides in or near to propagation environments.

AHDB Horticulture factsheet 25/12: ***Non-chemical weed control for container-grown nursery stock,*** provides further, more detailed guidance on cultural and other non-chemical weed control measures.

Herbicide options

Currently, there is only a single residual herbicide product, Flexidor 500 (isoxaben), which is approved for use on nursery stock grown under protected structures and can be considered to give pre-emergence control of a range of weeds in rooted cuttings and pot liners.

Flexidor 500 has a label approval permitting use on HNS under protection. However, several HNS subjects are sensitive to it and may be especially vulnerable in plug trays, where the rooting volume is more restricted and roots of cuttings are often near the surface.

A number of AHDB Horticulture screening trials have been carried out with this herbicide product to provide better information on its efficacy and crop safety when used on HNS under protection, including weaned cuttings in plug trays and pot liners. In early work with pot liners at HRI Efford (AHDB Horticulture project HNS 35b: ***Herbicide screening under protection***), *Lavandula* suffered a slight check to growth with Flexidor 125. Further work continued with liners and weaned cuttings in plug trays under protection (HNS 35g: ***Chemical weed control in container-grown nursery stock under protection***), with a wider range of species and treatments, including Flexidor 125 at the reduced rate of 1 litre/ha.

In HNS 35g, some species suffered reduced or delayed spring growth from summer applications of Flexidor 125 (this was more of a problem with plug trays, where the rooting volume is more restricted than with liners). *Buddleia* and *Lavatera* were damaged by treatments involving Flexidor 125, and *Clematis* also appeared sensitive, with reduced spring growth and even plant death. There were some indications that early winter applications were safer to sensitive species. Table 20 (overleaf) provides further guidance.

In terms of the weed spectrum controlled, Flexidor 500 has weaknesses notably, groundsel and willowherb. The product too cannot be relied upon for effective and sustained control of liverwort and moss. As a result of the limited number of applications which can be made per crop, cultural methods of weed control should play an important role in any weed control programme.

Table 20. Tolerance of protected HNS liners and weaned cuttings in plug trays to Flexidor 500

Herbicide	Flexidor 500
Approval status	Label approval
Berberis	Green
Buddleia	Red
Ceanothus	Green
Chaenomeles	Green
Choisya	Green
Cistus	Green
Clematis	Red
Cornus	Red
Cotoneaster	Yellow
Cytissus	Green
Escallonia	Green
Euonymus	Yellow *
Forsythia	Green
Hebe	Green
Hedera	Green
Hypericum	Green
Jasminum	Green **
Kerria	Green
Lavandula	Green
Lavatera	Yellow
Ligustrum	Green
Lonicera	Green
Osmanthus	Green
Parthenocissus	Green
Polygonum	Green
Potentilla	Green
Pyracantha	Green
Rosmarinus	Green
Santolina	Green
Senecio	Green
Spiraea	Green
Viburnum	Green
Vinca	Green
Weigela	Green

Red: Susceptible: Unacceptable crop damage normally occurs – do not treat

Yellow: Moderately susceptible: Some crop damage may occur but plants normally grow away

Green: Tolerant: Crop damage does not normally occur

Notes: Only a limited number of species and cultivars were tested within each genus, it is, therefore, essential to carry out small-scale trials on plants prior to full-scale treatment. For some subjects, the results are based on one year's trial only.

* Some cultivars have shown moderate susceptibility

** No damage recorded in these trials but occasional damage is known to occur

Weed control in outdoor seed beds

Safe and effective weed control in outdoor seed beds presents a significant challenge for HNS growers, complicated somewhat by the particular susceptibility of small seeded crops such as alder, birch, hawthorn and whitebeam to some herbicides and their vulnerability to weed competition while establishing.

Good nursery hygiene and crop husbandry are an essential starting point, helping to keep background weed pressures in surrounding non-crop areas such as headlands and pathways under control, aided by prompt hand weeding to remove weeds before they flower. Other control measures include the stale seed bed technique, soil sterilisation and the use of residual herbicides.

Both hand weeding and soil sterilisation are expensive for growers. Research, therefore, has focused on reducing these costs by trialling lower rates of Basamid (dazomet), the main soil sterilant now used by HNS growers following the loss of methyl bromide in 2005, and screening a range of residual herbicide products to use either as supplements to soil sterilisation or as an alternative, in pre- and post-crop emergence programmes.

Stale seed bed technique

This cultural technique can be used to attain weed-free seed beds prior to crop germination but must be done with great care, as correct timing is critical for it to be safe and effective. It involves using contact herbicides both before and after seed sowing to eradicate any weed seedlings present. The final application requires precise timing and should be made to catch the latest flush of weeds possible, at least three to four days before crop emergence. If applied too soon, subsequent weeds may be missed and, if applied too late, crop seedlings could be damaged. Done correctly, it is a timely and efficient method of cultural weed control but one that is short-term, in that there is no residual effect to maintain weed control beyond crop germination.

A number of contact herbicides including Reglone (diquat) currently have a label approval for use in this way, while the use of Shark (carfentrazone-ethyl) is via off-label approval (EAMU).

Soil sterilisation

Soil sterilisation is a common technique, usually done during the autumn prior to seed sowing in spring (although it can be done earlier for autumn sown crops). It has the added benefit of providing some control of soil-borne diseases and nematodes as well as weed seeds. However, successful soil sterilisation depends on several factors, including soil type, correct soil preparation, adequate soil temperatures and sufficient soil moisture.

Available as a granular formulation, Basamid (dazomet) can be applied relatively quickly and easily by rotary cultivation without the need for specialist contractors. On contact with moist soil, a gas is released and this must be retained by immediately sealing the surface, either by polythene sheeting (the preferred method), flooding with water to 'puddle' the soil surface or heavy rolling to compact the soil surface (only suitable for outdoor sterilisation in the autumn when followed by adequate rainfall to maintain a good seal).

After a period of 14 days in warm soils (10°C and above) or 28 days in cold soils, the seal is removed. The soil is then lightly cultivated to enable any traces of gas to disperse, taking particular care to avoid disturbing any unsterilised soil beneath the treated zone, otherwise contamination will occur. After a further 14 days (warm soils) or 28 days (cold soils), a standard safety test ('cress test') as per the product label should be carried out prior to any seed sowing or planting.

While reasonably effective, soil sterilisation can be expensive and AHDB Horticulture project HNS 31: ***Evaluation of weed control treatments in tree and shrub seed beds and first outdoor transplants,*** examined several herbicide treatments and the use of a low rate of Basamid application (100 kg/ha compared to the recommended rate of 380 kg/ha) raked into the top 5 cm of the seed bed surface. Both rates of Basamid worked well, with the lower rate achieving similar weed control levels to those of the recommended rate for at least two to three months following seed sowing, saving almost 75% on chemical costs. Both treatments also led to improved seed germination and seedling vigour.

If weed control is the principal reason for using Basamid, the reduced rate (100 kg/ha) applied to the top 5 cm of soil is a viable option and would provide considerable savings. However, the lower rate will not give adequate control of soil-borne fungal diseases and nematodes, should this be a further requirement. The use of Basamid is now restricted to application of no more than one year in three on the same site.

Residual herbicides

Currently, there are no residual herbicides with label recommendations specifically for use on nursery stock seed beds. However, there are currently off-label approvals (EAMU) for the use of Stomp Aqua (pendimethalin) and Goltix 70 SC (metamitron) both used at the grower's own risk.

Early work with herbicides

While some of the herbicide treatments in the seed bed element of HNS 31 gave good weed control in both years of the trial, they also caused a degree of crop loss and damage. AHDB Horticulture project HNS 31a: ***Tree and shrub seed beds: continued evaluation of weed control treatments*** developed this work over a range of HNS subjects, aiming to:

- Determine suitable application rates for the most promising herbicides identified in the original work, applied pre- and post-crop emergence
- Establish if lower rates of Basamid could be used in combination with herbicides applied post-crop emergence to achieve satisfactory levels of weed control

Unfortunately, the products that gave the highest levels of weed control, namely Butisan S (metazachlor), Flexidor 125 (isoxaben) and lenacil also caused the most crop damage, although some HNS species did show a reasonable level of crop tolerance. One approach when using the more effective residual herbicides with tolerant species is to apply them at low rates with top-up treatments as required. This system has been adopted by some HNS growers, with programmes based on low rates of Devrinol (napropamide) and Flexidor 500.

The three Basamid treatments (50 kg/ha, 100 kg/ha and 380 kg/ha) produced good levels of weed control with little difference between the 380 kg/ha and 100 kg/ha rates. The lowest rate initially gave a poorer level of weed control although this was improved by subsequent post-crop emergence applications of Flexidor 125, highlighting scope for combining low rates of Basamid with reduced rates of suitable herbicides such as Flexidor 125 and Butisan S (although application of the active ingredient metazachlor is now restricted to no more than 1 kg/ha in a three-year period on the same site). Such herbicide use is off-label and at growers' own risk.

Continued work with herbicides

Further trials work (AHDB Horticulture project HNS 155: ***Herbicide screening for tree seed beds***), screened a range of herbicide products at different application rates on different soil types for safe and effective pre- and post-crop emergence weed control, including single treatments and some tank mixtures. A selection of key small seeded species (*Alnus glutinosa, Betula pendula, Crataegus monogyna and Sorbus aucuparia*) and some with larger seeds (*Acer campestre, Cornus alba, Fraxinus excelsior* and *Rosa rubiginosa*) were included. At the same time, earlier herbicide research was published by Forest Research making further information available.

These later trials confirmed that formulations of pendimethalin (such as Stomp Aqua) are probably the safest of the residual herbicide options, with the widest range of species showing tolerance. However, for many of the small seeded species, the rate of use is relatively low (1 litre/ha) and this may compromise the level of weed control. Forest Research suggested the use of Stomp Aqua tank mixed with Devrinol for selected tolerant species as giving a good broad leaved weed control spectrum, although the use of Devrinol is limited to the period November to April.

The results from HNS 155 also suggested that Centium 360 CS (clomazone), Dual Gold (s-metolachlor) or Goltix WG (now Goltix 70 SC) could be used at low rates to improve the weed control spectrum of Stomp Aqua; the prevailing weed spectrum in the trials included annual meadow grass, black bindweed, fat-hen, groundsel, small leaf nettle, knotgrass, field pansy, mayweed, shepherd's purse and common speedwell. Results also suggested a possible role for Springbok (metazachlor+dimethenamid-P) but subsequent commercial experience has shown that unacceptable stunting can sometimes occur.

None of the treatments provided complete residual weed control throughout the life of the crop, although it was possible to maintain a reasonable level of weed control for the first two months when seedling crops are especially vulnerable to weed competition.

Post-crop emergence weed control using herbicides to keep seed beds clean is more difficult due to a greater risk of crop damage. HNS 155 did include a more limited series of trials testing post-emergence herbicides for crop safety and efficacy. The only experimental treatments to scorch, stunt or kill existing seedling weeds were Centium 360 CS, Dancer (phenmedipham, an EAMU currently covers use of a similar product, Corzal SC) and Goltix WG. The crop safety results are included in Table 21 (opposite). Treatments were made when the crop was at the cotyledon or cotyledon to two true-leaf stage and weeds were no larger than two true-leaves.

Full details of all treatments, timings, rates and crop tolerance can be found in the final project AHDB Horticulture reports for HNS 31, HNS 31a and HNS 155. Growers are advised to refer to these before applying any treatments and then, on a small-scale trial basis first, to check crop safety before wider use. Currently, Butisan S and Flexidor 500 (label approval) and Goltix 70 SC and Stomp Aqua (via EAMU) can be used over HNS post-crop emergence, although none have specific label recommendations for use over seed beds and such use is made at the growers' own risk.

Tank mixes were also considered for removing existing weed and maintaining weed control and the most effective were Dancer+Goltix WG and Dancer+Springbok. However, these were only safe on *Acer* and *Crataegus,* although the latter combination caused less loss of vigour.

Centium 360 SC was a safer post-emergence treatment and could be used on *Betula, Crataegus, Fraxinus* and *Sorbus*.

Successful weed control in seed beds containing *Quercus* and *Sorbus*

Table 21. Summary of the effects of a range of herbicides on tree and shrub germination and seedling growth

Herbicide product		Corzal SC	Butisan S	Centium 360 CS	Devrinol	Dual Gold	Flexidor 500	Goltix 70 SC	Intruder	Stomp Aqua	Venzar 500 SC
Approval status		EAMU	Label	EAMU	LTAEU	EAMU	Label	LTAEU	Label	EAMU	LTAEU
Pre or post (P) crop emergence		P	Pre/P	Pre/P	Pre	Pre	Pre/P	Pre/P	P	Pre	Pre/P
Acer campestre	Germination				Tolerant			Tolerant		Tolerant	
	Vigour/phytotoxicity	Susceptible			Tolerant			Tolerant		Tolerant	
Acer platanoides	Germination		Tolerant		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Susceptible		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Acer pseudoplatanus	Germination		Tolerant		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Susceptible		Tolerant		Susceptible	Tolerant	Tolerant	Tolerant	Susceptible
Acer rubrum	Germination		Susceptible		Tolerant		Susceptible	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Susceptible		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Alnus glutinosa	Germination		Susceptible	Moderately susceptible	Susceptible	Tolerant	Susceptible	Tolerant	Tolerant	Tolerant	Susceptible
	Vigour/phytotoxicity	Susceptible	Susceptible	Moderately susceptible	Susceptible	Tolerant	Susceptible	Tolerant	Tolerant	Tolerant	Susceptible
Betula pendula	Germination		Tolerant	Tolerant	Susceptible	Tolerant	Susceptible	Susceptible	Tolerant	Tolerant	Susceptible
	Vigour/phytotoxicity	Susceptible	Tolerant	Tolerant	Susceptible	Tolerant	Tolerant	Moderately susceptible	Tolerant	Tolerant	Tolerant
Carpinus betulus	Germination				Moderately susceptible					Susceptible	
	Vigour/phytotoxicity				Moderately susceptible					Susceptible	
Cornus alba	Germination							Tolerant		Tolerant	
	Vigour/phytotoxicity							Tolerant		Tolerant	
Cornus sanguinea	Germination				Moderately susceptible					Susceptible	
	Vigour/phytotoxicity				Moderately susceptible					Susceptible	
Corylus avellana	Germination				Tolerant					Tolerant	
	Vigour/phytotoxicity				Tolerant					Tolerant	
Cotoneaster franchetti	Germination		Susceptible		Tolerant		Susceptible	Susceptible	Tolerant	Tolerant	Susceptible
	Vigour/phytotoxicity		Susceptible		Tolerant		Susceptible	Tolerant	Tolerant	Tolerant	Susceptible
Crategus monogyna	Germination		Tolerant	Tolerant	Tolerant	Susceptible	Susceptible	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity	Tolerant	Tolerant	Tolerant	Tolerant	Susceptible	Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Fagus sylvatica	Germination		Moderately susceptible		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Tolerant		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Gleditsia triacanthos	Germination		Susceptible		Tolerant		Susceptible	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Tolerant		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Prunus avium	Germination		Tolerant		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Moderately susceptible		Tolerant		Susceptible	Tolerant	Tolerant	Tolerant	Susceptible
Prunus padus	Germination		Susceptible		Tolerant		Susceptible	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Susceptible		Tolerant		Susceptible	Susceptible	Tolerant	Tolerant	Susceptible
Quercus robur	Germination		Tolerant		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Moderately susceptible		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
Rosa rubiginosa	Germination							Tolerant		Tolerant	
	Vigour/phytotoxicity							Tolerant		Tolerant	
Sorbus aucuparia	Germination			Tolerant	Tolerant	Susceptible		Moderately susceptible		Tolerant	
	Vigour/phytotoxicity	Tolerant		Tolerant	Tolerant	Susceptible		Moderately susceptible		Tolerant	
Sorbus intermedia	Germination		Tolerant		Tolerant		Tolerant	Tolerant	Tolerant	Tolerant	Tolerant
	Vigour/phytotoxicity		Susceptible		Tolerant		Susceptible	Susceptible	Tolerant	Tolerant	Susceptible

- Susceptible: Unacceptable crop damage normally occurs – do not treat
- Moderately susceptible: Some crop damage may occur but plants normally grow away
- Tolerant: Crop damage does not normally occur

Label — Label approval for use on HNS

EAMU — Off-label approval via an Extension of Approval for Minor Use (growers' own risk)

LTAEU — Off-label approval under the Long Term Arrangements for Extension of Use (growers' own risk)

Table 21. Summary of the effects of a range of herbicides on tree and shrub germination and seedling growth (continued)

Product	Active ingredient and concentration	Product rates
Corzal SC	Phenmedipham (160 g/l)	2.5 litres/ha
Butisan S	Metazachlor (500 g/l)	1.5 litres/ha
Centium 360 CS	Clomazone (360 g/l)	0.125–0.250 litres/ha
Devrinol	Napropamide (450 g/l)	2.2–5.0 litres/ha
Dual Gold	S-metolachlor (960 g/l)	0.8 litres/ha
Flexidor 500	Isoxaben (500 g/l)	0.8 litres/ha
Goltix 70 SC	Metamitron (700 g/l)	1.5–3.0 litres/ha
Intruder	Chlorpropham (400 g/l)	2.0 litres/ha
Stomp 400 SC equivalent to Stomp Aqua	Pendimethalin (400 g/l) Pendimethalin (455 g/l)	1.0–3.0 litres/ha 0.88–2.64 litres/ha
Venzar 500 SC	Lenacil (500 g/l)	0.4 litre/ha

Post-rooting nutrition

Healthy, well-rooted cuttings that are uniform and true to type are the essential starting point of high-quality production. However, they and seed raised material often remain in their trays for lengthy periods and can become starved before potting on, particularly in the absence of controlled release fertilisers. This leads to delayed establishment, slower growth, increased susceptibility to pest, disease and weed problems and poor overall uniformity, which is often reflected in the final grade out.

Although work has been undertaken on post-rooting nutrition, these difficulties also underline the importance of accurate demand forecasting and record-keeping.

For best results, adequate and balanced nutrition is essential throughout the propagation process. Very quick growing crops are unlikely to require much supplementary nutrition, provided the plants from which propagation material is taken are in good condition.

Controlled release fertilisers

Considerable work has been done with the incorporation of controlled release fertilisers in propagation media, to provide gradual nutrition during and following rooting of cuttings.

While the nutrient release of such products is temperature related and high temperatures can trigger ‘flash’ release, which may damage young roots, the inclusion of bark in the rooting medium enables their safe use, at low rates, in propagation situations.

With loose-filled and pre-formed modules, mini-granule controlled release fertilisers ensure safe and uniform distribution. Such products are, however, relatively short-term and supplementary feeding will be required for longer-term crops.

The inclusion of low rate controlled release fertilisers with bark in the propagation medium deliver safe and gradual nutrition

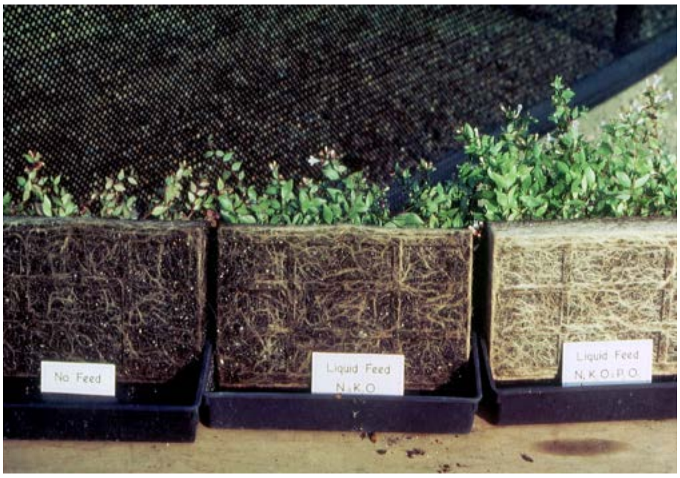
Liquid feeding

Early work at HRI Efford, before the arrival of controlled release fertiliser nutrition, investigated ways of maintaining and improving the quality of rooted material prior to potting. Initial trials used different liquid feed treatments, beginning four weeks after cuttings had been weaned and continued through until potting on:

- 50 ppm nitrogen + 50 ppm potassium applied every 1–2 weeks depending on frequency of watering
- 50 ppm nitrogen + 50 ppm phosphate + 50 ppm potassium applied every one to two weeks as above

The trials used a range of autumn struck cuttings (including: *Berberis stenophylla,* various *Chamaecyparis, Cytisus, Elaeagnus, Ilex* and *Viburnum x burkwoodii)* rooted under polythene. Rooted material was weaned and then held under cold glass before potting in late spring.

In all cases, there was a striking improvement in quality and growth of cuttings where a feed programme had been used following weaning, relative to the untreated control. The nitrogen and potassium feeding regime maintained cutting quality without excessive growth occurring (enabling cuttings to be successfully held in trays) while the nitrogen, phosphate and potassium regime promoted rapid early growth in the tray, as well as maintaining quality (although earlier potting was required to prevent overcrowding in the tray).



The benefit of post-rooting nutrition using liquid feeding (middle and right trays)

The effects of feeding became more pronounced the longer the cuttings were held in the trays. While the cuttings established satisfactorily from all treatments, the nitrogen and potassium, and nitrogen, phosphate and potassium fed material grew away faster and more uniformly than the non-fed cuttings. The effects were still visible some six months after potting on, especially where phosphate had been included.

The benefit of nutrition during weaning and after: cuttings to the left no feed and to the right with liquid feeding

Table 22 summarises the effects of the different feeding treatments from the final trial in this series of work.

Table 22. Effects of liquid feeding treatments on plant growth six months after potting, dry weight (g/plant)

Species	Time of potting	Feed treatment after rooting		
		Nil	N:K	N:P:K
Elaeagnus pungens 'Maculata'	June	2.4	2.6	2.9
	August	0.8	0.8	1.0
Viburnum burkwoodii	June	2.9	5.0	5.4
	August	1.5	1.7	2.4
Chamaecyparis lawsoniana 'Ellwoods Gold'	June	8.1	8.8	8.9
	August	2.0	2.1	3.4
Chamaecyparis pisifera 'Boulevard'	June	5.3	5.8	6.2
	August	1.1	1.3	2.3
Chamaecyparis pisifera 'Squarrosa Sulphurea'	June	8.0	8.2	9.0
	August	1.3	1.8	2.3

One of the difficulties, however, with liquid feeding during the autumn and winter period is the limited requirement of rooted cuttings for water, making it easy to waterlog them unless frequency of application is reduced, so limiting the amount of feed that can actually be applied.

Nutrition of rooted cuttings in modules

Supplementary feeding to maintain cutting quality following rooting, while clearly beneficial, can be |difficult with small volume modules, particularly when such material has to be held for lengthy periods prior to potting on. Not feeding leads to nutrient starved plants while weekly feeding with a balanced regime may create excessive growth and unwanted competition among cuttings in the tray. Omitting phosphate helps to avoid excessive growth while preserving foliage colour, enabling rooted cuttings to be held for lengthy periods before potting on.

However, cuttings can become rather hard and inactive after periods of phosphate restriction and, to address this, AHDB Horticulture project HNS 90: ***Nursery stock propagation: nutrition of rooted cuttings in modular trays***, aimed to appraise the potential benefits of liquid feed regimes with and without phosphate on module rooted cuttings held for lengthy periods before transplanting, compare the effects of using controlled release fertiliser mini-granules in the rooting medium with liquid feed regimes on plant quality following potting and assess the effect of nutritional composition and treatment regime on the effectiveness of nutrient 'trigger' treatments (a pre-potting liquid feed to encourage plant growth).

These were liquid feed regimes with phosphate applied shortly before potting, with the aim of promoting active growth after potting on.

The work used winter struck cuttings (*Choisya ternata* and *Juniperus communis* 'Repanda') and summer struck cuttings (*Azalea* 'Rose Greeley' and *Cotoneaster dammeri* 'Coral Beauty') rooted in peat:bark in small plug (55 ml) module trays. Rooted cuttings were held for either three months (winter struck cuttings) or five months (summer struck material) and during this period given supplementary nutrition either by liquid feed or controlled release fertiliser mini-granules.

Each of the treatments also received 'trigger' nutrient treatments prior to potting into a pre-mixed peat-based growing medium.

Effects of liquid feeding

Three feeding regimes were assessed, including: no liquid feed (control), 50 ppm nitrogen + 50 ppm potassium applied every two weeks and 50 ppm nitrogen + 25 ppm phosphate + 50 ppm potassium also applied fortnightly. Final observations were made four months later.

Liner plant quality was not improved in any of the species by the nitrogen and potassium treatment (although, as highlighted earlier, it does maintain cutting quality without generating unwanted extension growth and crowding in the tray). In contrast, the inclusion of phosphate gave very marked quality improvements in all four species; plants were generally bushier, larger and had greater dry weights (except *Juniperus*).

Effects of controlled release fertilisers

Mini-granules were incorporated into the rooting medium at 0.5 kg/m^3 (winter struck cuttings) and 0.75 kg/m^3 (summer cuttings) and compared with an untreated control and liquid feed treatment (50 ppm nitrogen + 25 ppm phosphate + 50 ppm potassium). No additional liquid feed was applied to the controlled release fertiliser treatment while the rooted cuttings were being held, but nutrient trigger treatments were given (200 ppm nitrogen + 150 ppm phosphate) six weeks before potting on.

Overall, in comparison to the untreated control, the controlled release fertiliser was significantly beneficial in the winter struck *Choisya* and *Juniperus* but of no or little benefit in the summer propagated *Azalea* and *Cotoneaster.* The reasons for the latter result were unclear but it may have been related to the diminishing effect of the controlled release fertiliser following (earlier) summer propagation. When comparing the controlled release fertiliser with the liquid feed programme, the latter treatment was of great benefit with *Cotoneaster* and *Azalea*, while the controlled release fertiliser was better with *Choisya* and *Juniperus*. The apparent species specificity arising from these results may, however, have been more related to the time of year when the cuttings were struck. Thus, the two species benefiting most from the controlled release fertiliser treatment were both winter struck and so had a relatively short holding period before potting. The summer struck *Cotoneaster* and *Azalea,* with the longer holding period, did not show any benefit, suggesting that the controlled release fertiliser had supplied all its available nutrients by the end of the period and was out-performed by the liquid feed treatments.

Controlled release fertiliser mini-granules can normally be expected to provide nutrients for three to four months depending on seasonal conditions and cultural regimes. When the holding period exceeds this, a follow-on liquid feed regime is required to maintain cutting quality.

Effects of trigger treatments

Four nutritional triggers were also assessed, comprising two levels of nitrogen (100 and 200 ppm) and two levels of phosphate (150 and 300 ppm). Each was applied two or three times, with two weeks between successive applications. Trigger applications began either six weeks before potting, when three applications were given, or four or six weeks before potting when two applications were given.

There were no major trends between the treatments or indication that a trigger treatment can compensate for the reduced growth and quality arising from a 50 ppm nitrogen + 50 ppm potassium maintenance feed rather than one with the addition of 25 ppm phosphate. On the basis of this work, trigger treatments are not recommended as substitutes for maintenance feeding using a balanced nutrient feed containing phosphate.

Cultural suggestions

As a result of the above and other research work, the following cultural recommendations can be made:

- Ensure stock plants and nursery crops used for propagation material have adequate nutrient reserves to maintain strong, healthy growth suitable for use as quality cuttings
- Liquid or foliar feed quick growing container stock plants ahead of propagation to boost nutrient reserves for rooting. Continue this programme through rooting, weaning and thereafter. Avoid an excess of nitrogen, which will reduce rooting
- When devising feeding regimes consider the vigour and requirements of crops, the propagation and weaning environment, the rooting medium and the fertiliser used
- Use rooting media with controlled release mini-granules incorporated when rooted cuttings are expected to be held for a significant period before potting on
- Use a balanced liquid feed at two-week intervals if rooted cuttings with controlled release fertiliser mini-granules are held beyond this period
- With slower rooting autumn propagated material, controlled release fertilisers provide sustained and balanced post-rooting nutrition efficiently over a longer timeframe
- Longer-term, crops rooted during the spring and summer period and overwintered also benefit from the inclusion of controlled release fertiliser but should also be potted promptly. Ensure controlled release fertiliser is uniformly incorporated within the rooting medium

- For short-term crops, the inclusion of controlled release fertilisers is not essential, providing the nursery is geared up to regular liquid feeding

Growth control

It is often necessary to control the growth of rooted cuttings and young liners either to maintain or improve their quality or to schedule them. Pruning and trimming of propagation and liner crops is widely practiced and there is some use of chemical plant growth regulators with the latter, but there is also a wide range of cultural alternatives for controlling growth, including:

- Growing more compact or slower growing species
- Scheduling plant production
- Controlling environmental temperatures
- Controlling light intensity and quality
- Managing the frequency and amount of irrigation provided
- Manipulating nutrition and employing nutrient restriction
- Restricting growth by physical means
- Using cold storage facilities
- Using outdoor production facilities

Pruning of liners and plug plants

Pruning and trimming of rooted cuttings and liners to reduce plant height and shape young plants is a crucial part of quality production, particularly with quick growing, vigorous subjects and in the absence of other forms of growth control. It is also important where the potting on of rooted material or young liners is delayed to prevent excessive growth. Traditionally undertaken by hand, machinery is now available to ease and speed up the work, some of which also collects pruned plant material as the work proceeds.

Timing is often critical. With most conifers and shrubs responding well to being pruned when actively growing, for example, as a liner in midsummer. However, if this is done later in the season, so forcing new growth that doesn't have time to ripen, winter losses or plant death may ensure. Any formative structural pruning with spring and early summer propagated material should be done in midsummer, with only light trimming to tidy taking place during the autumn.

AHDB Horticulture project HNS 40: ***Pruning for quality with minimum reduction in size***, aimed to understand more about how plants respond to different pruning techniques and so identify strategies by which quality can be enhanced; a key consideration was that pruning should not reduce plant size unnecessarily. Results showed that while different species responded differently to pruning, some guiding principles could be derived in relation to vigour of growth in each species.

Generally, the more vigorous the species, the greater the pruning benefit in terms of bud development and new basal branch formation. Severe pruning was usually detrimental to slower growing subjects such as *Cotinus, Garrya* and *Viburnum*, delaying branch formation and significantly reducing overall plant size. Timing was also critical, with severe autumn or winter pruning making less vigorous plants more susceptible to overwintering stresses. For these subjects, no pruning or light pruning was often the best treatment, although the frequency of pruning to promote optimum growth characteristics could still vary with species, for example, *Syringa* was best pruned once, *Garrya* three times.

Although this work focused on larger plant material, it also has implications for liner and large plug plant producers.

Regular trimming is an important part of quality plant production

Chemical plant growth regulators

Plant growth regulators are chemical compounds that alter growth and development by modifying the plant's natural hormone balance. Sometimes, it is more appropriate to use chemical plant growth regulators to attain the desired results rather than cultural methods, however, they should not be used as a substitute for good crop culture.

The products should be applied at a particular physiological stage in the development of the plant and not scheduled by time. A programme of treatments is usually required with most crops; they should not be applied when growth has already become excessive or too advanced.

Currently, products used in the UK are based primarily on three main active ingredients. Stabilan 750 contains chlormequat, B-Nine SG and Dazide Enhance contain daminozide and Bonzi and Pirouette contain paclobutrazol. A further product, Regalis Plus, which contains prohexadione-calcium, can also be used in ornamental plant production via an EAMU. They keep plant height in check by reducing the stem internode length but they also have an effect on branching, plant habit, foliage colour and flowering.

Experience with growth regulators and pot liners is quite limited, although some growers use low rate sequential programmes of products to control growth under protection, once a basic branch framework has been established. There is also some use of products for growth control in herbaceous perennials grown for retail sales.

There may be scope to adapt these programmes for use with rooted HNS cuttings and liners, where growth control under protection is required. B-Nine SG or Dazide Enhance give moderate growth control and they are likely to be the most suitable for use in young plant production, rather than Bonzi or Pirouette whose effects are relatively more intense.

Choice of species or variety

Where feasible and practical, compact or low vigour species or varieties should be selected and grown to reduce the need to resort to any kind of growth control. This is a simple yet useful guiding principle to be aware of. However, choice of species or variety is usually determined by sales requirements, and they are often selected for attributes other than vigour that may offer a commercial advantage.

Accurate plant scheduling

Scheduling aims to match supply with demand and, therefore, minimise crop wastage. By propagating to a production programme on planned, sequential dates and controlling the growing environment accordingly, plants can be produced to the agreed specification when required. However, seasonal weather conditions invariably determine market demand and can, in turn, delay the handling of rooted cuttings or liners. Transplanting vigorous crops later in the season is a simple and practical way of controlling growth.

Controlling environmental temperatures

Lowering the mean growing temperature can also be an effective way to restrict or delay growth with propagation and liner crops grown under protection, although this will slow down plant development and increase production times. Conversely, raising the temperature, by reducing ventilation or using space heaters, will usually advance growth but care is required to avoid soft, excessive growth.

Controlling light intensity and quality

Low light levels cause plants to stretch and so reduce quality, therefore, light transmission levels through glasshouses and polythene tunnels need to be maximised. Clean, good quality glass transmits around 88% of light but shadowing from structural frameworks and thermal screens, etc. will reduce this. Dirty glass will reduce light transmission further (typically, by about 20%), while dirty polythene can reduce light transmission even more (up to 30%). Plants are also sensitive to light quality as well as light intensity; increasing the UV, blue or the red to far red ratio of light, for example, can all contribute towards growth control.

Spectral filters

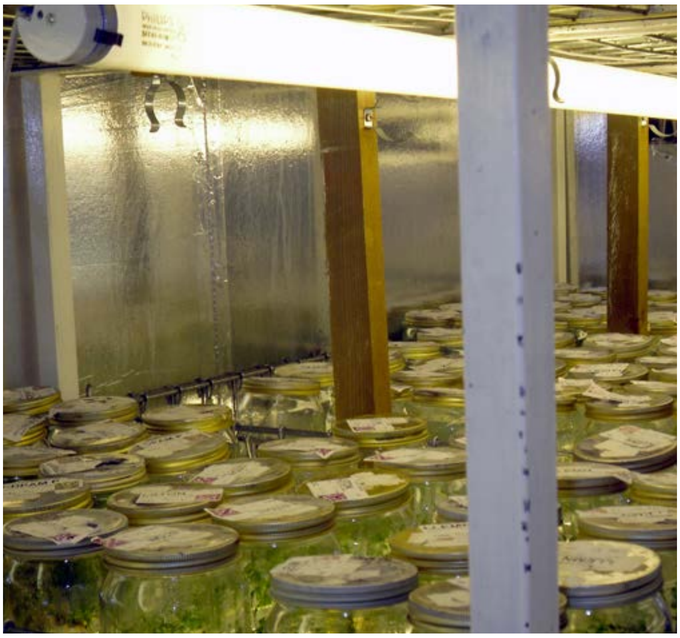
Plastic films with different light spectral transmission properties have been developed, which can be used as a means of controlling growth, flowering time and foliage colour with some HNS species. These films alter the wavelength of light passing through them and have been shown (for example, in AHDB Horticulture project HNS 108: ***Growth of a range of nursery stock subjects under different coloured and spectral filter films***), to reduce plant height, increase branching and increase leaf colour intensity in a range of plant species. However, the intensity of their effects varies with species.

In a parallel study, the rooting of cuttings taken from plants grown under spectral filters was also evaluated. For the majority of the species tested, altering the light spectrum over the stock plants appeared to have very little effect on the rooting percentage of cuttings taken from them. With the exception of the usually difficult to root *Cotinus* and the slow rooting conifer, *X Cupressocyparis leylandii,* rooting percentages tended to be high regardless of treatment.

Artificial lighting

Artificial lighting has been used in commercial horticulture for many years to enhance natural light levels and extend day length, thereby improving plant quality and enabling the programmed production of protected crops, most notably bedding plants, pot plants and cut flowers. Essentially, there are three different techniques or approaches used for lighting crops:

- Supplementary lighting: this is photosynthetic lighting and involves the use of high intensity lighting (5,000–15,000 lux) to enhance natural light levels by adding artificial light to natural daylight or by extending the natural day into the night period or a combination of both to promote plant growth. Usually, high pressure sodium lamps are used for this purpose. It is used with nursery stock under protection, for example, to aid seed germination, shorten production times and improve quality
- Photoperiodic lighting: this is non-photosynthetic lighting. As such, a much lower (around 50 lux) light intensity is used to manipulate rather than supplement natural daylight and so stimulate out of season responses for many species, particularly in respect of flowering and dormancy. It is used to extend natural day length either at dusk or dawn or by a period of light that breaks the night into two dark phases (‘night-break’ lighting)
- Replacement lighting: this differs from supplementary and photoperiodic lighting in that it is deployed to either totally or partially replace daylight with artificial light. Most usually it takes place in an insulated growing or germination room from which natural daylight is excluded. Such structures are widely used for seed propagation and, in micropropagation, where the principal objective is to achieve rapid and uniform germination or root initiation using a high degree of control over the light environment



Growth chambers provide close control of growth

Light application to stock plants

Supplementary lighting can be used to advance the growth of stock plants to extend the propagation season and enable a greater number of cuttings to be harvested from each plant.

In HNS 42 and 42a: *Supplementary lighting for alpines, herbaceous and hardy nursery stock species*, early growth on 3-litre *Clematis* 'Miss Bateman', grown as stock plants in a 16-hour photoperiod with high pressure sodium lamps, enabled cuttings to be taken earlier than from those grown in an 8-hour day, indicating wider potential for manipulating stock plant growth.

Effects of light application to stock plants on subsequent rooting of cuttings

Other studies have also considered the effects of the photoperiod to which stock plants are subjected on the subsequent rooting of HNS cuttings. Cuttings of *Cornus florida,* for example, (Waxman, 1957) taken from stock plants grown for four months under a 15-hour photoperiod rooted better than those from stock plants grown for the same duration under a 9-hour photoperiod and similar results have been reported with *Rhododendron obtusum japonicum* cultivars 'Hinodegriri' and 'Snow' (Barba and Pokorny, 1975). However, the rooting of cuttings of *Ilex crenata* 'Hetzii' improved as increasing numbers of short days were given to stock plants grown during the summer (Kelly, 1965) and *Taxus cuspidata* 'Nana' has been shown (Lamphear and Meahl, 1963) to root best when cuttings are taken between November and February (during natural short days).

Light application at rooting

American research work has shown that some HNS species will root better and quicker when given long day lighting during propagation, including cultivars of *Abelia, Cornus, Ilex* and *Magnolia*. Anecdotal UK experience also indicates success with *X Cupressocyparis leylandii, Chamaecyparis lawsoniana* cultivars, *Juniperus horizontalis* 'Glauca', *Thuja occidentalis* 'Rheingold' and *Thuja orientalis* 'Decussata' when lit during rooting.

More specific studies with selected species have also considered the responses of cuttings to photoperiodic lighting given during rooting but results have been variable. In work with *Cornus florida* cuttings (Waxman 1955,1965) inserted under mist during June, root numbers increased with day lengths of 18 or 24 hours compared with 9 hour or natural day length treatments, although the percentage rooting was the same throughout (Table 23).

Table 23. The effect of photoperiodic treatment on the rooting of *Cornus florida* cuttings (Waxman, 1955, 1965)

Photoperiod	Percentage rooting	Average number of roots per cutting
Normal day length	100	15.4
9 hours	100	8.50
18 hours	100	25.4
24 hours	100	23.7

Similarly, in more detailed studies with *Cornus alba* (Whalley and Cockshull, 1976), there was little difference in percentage rooting when cuttings were given long day treatments of continuous light (dusk to dawn) or a 5-hour night-break, in comparison with natural day lengths. The main effect was a subsequent increase in stem growth of plants rooted under long days.

When cuttings were taken in the autumn (when the natural day length was shorter), root number and percentage rooting were increased by long day treatments; this also applied to cuttings of *Berberis ottawensis* 'Superba' and *Viburnum x bodnantense* 'Dawn' when taken in the autumn (Whalley and Cockshull, 1972).

It is well known that indoleacetic acid (IAA, a naturally occurring auxin-based plant hormone that promotes rooting) levels may be increased by long photoperiods in both stem and leaf tissue. However, the relationship between this and enhanced rooting promoted by photoperiod is not completely understood.

Work at Loughall (1978–1979) also considered the effects of supplementary and photoperiodic lighting (night-break) on the rooting of a range of autumn struck evergreen species (*Berberis candidula, Berberis x stenophylla, Ceanothus, Elaeagnus x ebbingei, Escallonia, Euonymus, Ilex, Pittosporum, Pyracantha, Senecio and Viburnum tinus)* and conifers (*X Cupressocyparis leylandii, Cupressus macrocarpa* 'Lutea', *Chamaecyparis lawsoniana* cultivars, *Juniperus communis* and *Thuja occidentalis*) under mist, with the subjects being grown on to a finished plant to assess the full effect of the treatments.

Cuttings were placed under high pressure sodium, low pressure sodium and tungsten filament lamps and an unlit control. The sodium lamps were positioned to provide a luminance level of 10,000 lux and used over an 8-hour period from 8:00am to 4:00pm to supplement natural daylight. The tungsten filament lamps were used to provide photoperiodic night-break lighting, giving a minimum light level of 50 lux operated from 11:00pm to 2:00 am.

Only a limited number of subjects responded positively (higher percentage rooting compared to the unlit control) to photoperiodic (night-break) lighting (although increased speed of rooting was recorded in all subjects) and several gave a negative response (lower percentage rooting compared to the unlit control). However, nearly all subjects showed a positive response to supplementary lighting when propagated during the autumn. As in previous years, some varietal differences in response between low and high pressure sodium lighting were seen. In general, the former gave the better results. Some subjects, notably *X Cupressocyparis leylandii,* failed to respond to any form of lighting and *Viburnum tinus* gave a negative response to all lighting regimes.

The growth (measured as mean height) of the subsequent liners in their respective treatments was recorded the following year in April, immediately before potting into their final bag-pots (2.5-litre). The results, at this point, indicated that most cultivars when subjected to photoperiodic lighting produced a larger liner than the control but supplementary lighting produced smaller plants. Plants given supplementary lighting during rooting had shorter internodes and, in some cases, larger leaf numbers. Photoperiodic lighting and, to a lesser extent, supplementary lighting was thought to have caused some flower buds to have aborted.

Records of plant height taken later at the end of the first growing season, showed that, for many subjects, plants that received supplementary lighting went on to produce larger plants. In 18 subjects, however, no significant difference was recorded between treatments. *Ilex aquifolium* was slow to break in the spring following exposure to supplementary light. The size and quality of all the other subjects at point of sale were equal to or better than the control.

The use of artificial lighting to promote rooting of several HNS subjects was also examined at HRI Efford in a trial using low intensity night-break lighting. In this case, applied from 10:30pm to 3:30am each night from insertion until weaning, using 60 W tungsten filament bulbs with reflectors spaced at 2 m centres, approximately 60 cm above the cuttings. The cuttings were taken during October and November and rooted under glass with clear polythene using a basal temperature of 18°C.

Table 24 summarises the results and shows positive responses from the Lawsons cypress cultivars ‘Allumii’ and ‘*Columnaris Glauca*’. Similarly, *X Cupressocyparis leylandii* showed a marked improvement in rooting with night-break lighting.

Given current (high) energy costs, it would only be economic to produce the most difficult subjects using supplementary lighting. Photoperiodic lighting, however, may be of interest at a later stage of propagation following callus formation.

Table 24. Effects of day length extension on the rooting of conifers

Species	Percentage rooting		Time difference to weaning (days)
	Lit	Unlit	
Chamaecyparis lawsoniana ‘Allumii’	57	38	43
Chamaecyparis lawsoniana ‘Ellwoodii’	87	80	29
Chamaecyparis lawsoniana ‘Ellwood’s Gold’	65	74	14
Chamaecyparis lawsoniana ‘Fletcheri’	15	45	43
Chamaecyparis lawsoniana ‘Columnaris Glauca’	93	35	54
X Cupressocyparis leylandii	30	12	14

Controlling the frequency and amount of irrigation

Reduced moisture regimes, where plants are irrigated little and often, and allowed to become stressed between irrigation cycles, will slow growth and produce a more compact plant habit (reductions in height of over 30% have been commercially achieved). However, the regime needs careful monitoring as excessive stress can stunt plants, cause premature flower bud drop and reduce plant quality. Sophisticated moisture probes are now available to help monitor the moisture levels in container-grown crops, see AHDB Horticulture project HNS 97: ***Improving the control and efficiency of water use in container-grown hardy ornamental nursery stock***. Such probes can also be connected to irrigation systems, providing a degree of automatic irrigation geared to the needs of the plant.

Nutrition and nutrient restriction

Excessive growth can be avoided by using appropriate amounts of the correct types of fertiliser. Low levels of base fertiliser in the growing medium, for example, will prevent rapid, early growth and controlled release fertilisers can be used to provide nutrients as the plant requires them or supplementary liquid feeds can be used and matched to the stage of crop development.

Controlling growth by physical means

This approach has its limitations but restricting the root systems of plants by, for example, holding them in modules or small pot sizes will constrain plant growth.

However, this needs to be carefully managed to avoid starvation. Growth imbalances can also still occur if other physical and environmental conditions are not addressed.

Cold storage

Rooted plugs can be held in cold storage for several days and even weeks to keep growth in check, so minimising the amount of bed space used to hold material back without a significant loss in quality. Longer-term, storage over several weeks also enables production to be scheduled to meet specific timeframes that might otherwise be difficult to achieve.

The feasibility of using cold storage as a scheduling aid with HNS was considered in AHDB Horticulture project HNS 113: ***The feasibility of using low temperature storage as a scheduling aid in nursery stock production***. The ability to hold rooted cuttings in modules and pot liners for short periods until required was one of several benefits identified during the study, enabling, for example, the development of scheduled potting programmes.

Although little work has been done to determine more precisely the cold storage temperature requirements of HNS species when stored as plugs or liners, 3–4°C is likely to be a good starting point.

Cold storage is also a useful management tool for container-grown stock plants, for example, to delay growth, and so propagation material, until it is required.

Either direct cooled or jacketed stores can be used, although the latter is more suitable, particularly for longer-term storage and where plants are unwrapped and so more prone to drying out if in a direct cooled store.

The AHDB Horticulture ***HNS Cold Storage – a grower guide*** and factsheet 09/05: ***Low temperature storage of bedding plant plugs***, provide more detailed guidance on the use of controlled temperature storage and are useful points of reference when considering this technique with HNS plug plants and liners.

Outdoor production

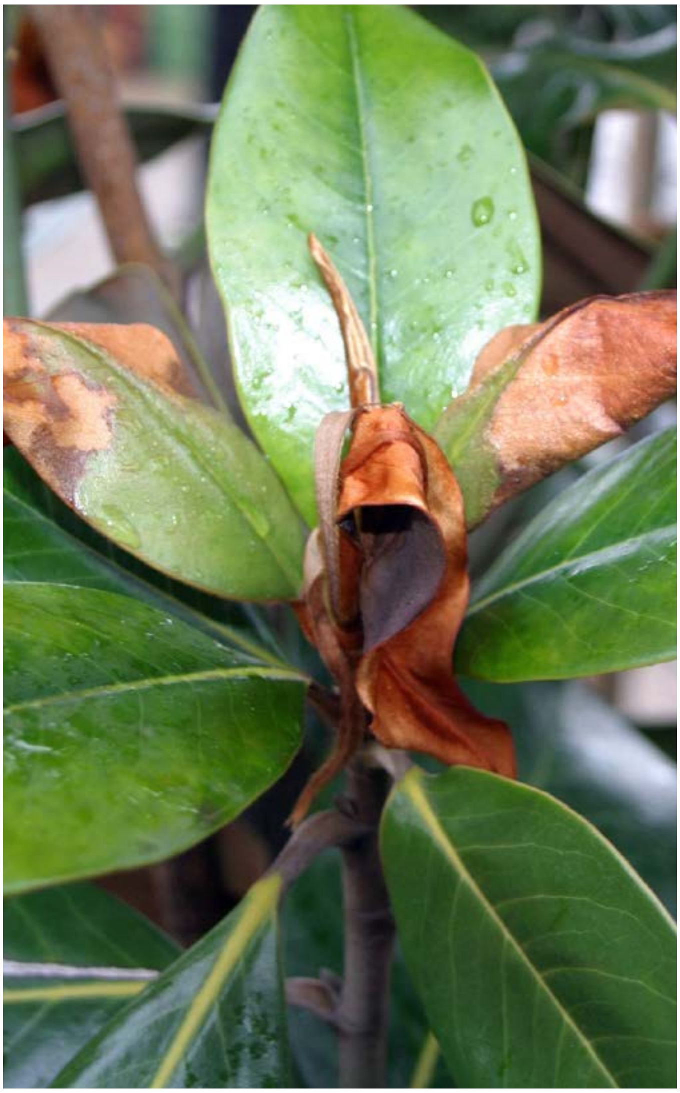
Moving protected crops to cooler, outdoor locations is also a useful way of controlling growth; such material is less likely to stretch than if it were grown entirely under protection and growth rates will slow down. Polythene tunnels can be uncovered in summer to save handling, either manually or by automated roof systems. Roll-out bench systems are another, flexible option, enabling crops to be quickly moved when required.

Overwintering of rooted cuttings and young liners

Rooted cuttings and young HNS liners are frequently overwintered under protection for potting on the following season, particularly spring and summer propagated material. Such material can fail to establish and sometimes dies during the first winter or is of reduced quality and vigour the following spring.

While the extent of failure may vary considerably between years, plant species and situation, most usually the two principal causes of this are:

- Direct injury to young plant tissue following exposure to sub-zero temperatures, often where frost protection measures were inadequate
- Indirect injuries in which tissues are exposed to prolonged but less severe, environmental stress



Frost damage is one of the main causes of poor winter survival among rooted cuttings and liners

The ability of cuttings to overwinter successfully appears to be strongly species-specific, with failure often associated with some of the more difficult, higher value HNS subjects, including *Acer (palmatum*), *Camellia, Corylopsis, Daphne, Garrya*, *Magnolia, Rhododendron* and *Viburnum* although even in some of the easier-to-root subjects (such as *Ceanothus*, *Choisya* and *Hebe*), prolonged stress in winter will reduce cutting and liner quality, particularly in the spring.

Waterlogging, frost damage and poor environmental control (notably, unsuitably high relative humidities around dormant cuttings creating ideal conditions for leaf diseases and damping-off) are a common but avoidable source of problems. Good crop husbandry, adequate frost protection and prompt application of crop protection measures are essential for successful overwintering.

Good nursery hygiene is also paramount, including routine monitoring of cuttings and prompt removal of decaying material. Propagation media and beds should also be clean and well drained.

Overwintering failure with rooted cuttings

AHDB Horticulture project HNS 44: ***Pre- and post-rooting storage of softwood and hardwood cuttings***, investigated the reasons for overwintering failure in newly rooted cuttings. Four subjects considered to be difficult to overwinter (*Acer palmatum* 'Aureum', *Ceanothus* 'Autumnal Blue', *Euphorbia griffithii* and *Magnolia x soulangeana*) were rooted in plug trays and overwintered in polythene tunnels, glasshouses or cold stores.

Temperature and humidity

While the effects of various overwintering stresses varied with species, in general, exposure to simulated frost was most detrimental. Even light frosts resulted in leaf or stem damage and growing media temperatures of -3°C invariably led to plant death, regardless of species or depth of dormancy.

Other stresses were also critical; *Ceanothus* was especially sensitive to even moderate levels of desiccation and *Acer palmatum* was prone to injury associated with high overwintering temperatures (15–20°C) when grown in heated glasshouse structures. Losses with *Euphorbia* were also associated with high humidity during the project. Cold storage enhanced cutting viability and led to greater subsequent vigour in some cases, for example, faster and stronger growth of *Ceanothus* and *Magnolia* compared to rooted cuttings overwintered under polythene.

Rooting and nutrition

Generally, cuttings that are poorly rooted prior to winter are more likely to fail, even though stems may appear viable and healthy for many weeks following weaning.

Losses can still occur with well-rooted cuttings not subjected to significant stress, usually due to selection of poor quality or second grade cuttings, or as a result of rooting cuttings too late in the season or under less than ideal conditions. While rooting rates may be high in such material, carbohydrate reserves are often quite limited and unable to sustain cuttings successfully overwinter. Preferably, cuttings should be selected only from the youngest, most vigorous stock plant material.

A failure to form strong, well-developed roots before winter underlines the importance of timely propagation and liner potting to allow adequate time for new roots to fully establish before the dormant period. This is particularly so with less vigorous, slower rooting deciduous subjects, which are also thin stemmed, such as species or cultivars of *Acer palmatum, Berberis, Cornus, Corylopsis, Potentilla* and *Spiraea,* for example.

Strong, well-developed roots are one of the keys to successful overwintering of cuttings

Adequate nutrition of stock plants, cuttings (during and after rooting) and liners following potting is also an essential component of successful overwintering; malnourished material will struggle to establish adequately and so will not survive.

Overwintering strategies

Further work (AHDB Horticulture project HNS 84: ***Development of effective overwintering strategies for rooted cuttings and young liners***), considered in greater detail why rooted cuttings often fail to establish and then die during their first winter (many of these losses occur following rooting and during the early stages of liner production), focusing on indirect injuries brought about by prolonged exposure to environmental stress.

In such cases, no immediate injury is sustained but resources within plant tissues gradually decline or cell viability becomes impaired leading to a failure of buds to break dormancy the following spring. The work aimed to determine more fully what environmental stresses contributed to winter losses under protection and the extent to which factors before or during rooting affected winter survival.

A range of subjects considered difficult to overwinter were used for the project, comprising *Acer palmatum* 'Bloodgood', *Acer palmatum* 'Aureum', deciduous *Azalea*, *Ceanothus* 'Autumnal Blue' (representing evergreen species where loss of foliage quality can be significant in winter), *Corylus pauciflora*, *Cotinus coggygria*, *Magnolia x soulangeana, Rhododendron* 'Coccineum Specoisum' and *Viburnum carlesii* 'Aurora' (Table 25).

The project found the following factors significantly affected rooting and winter survival rates:

- The extent to which the stock plants were pruned
- The type and size of cutting
- The part of the stock plant from which cuttings were taken
- The handling of cuttings following collection
- The overwintering environment
- The type and extent of covering material used for frost protection

Often these factors influenced survivability, irrespective of rooting percentage. For example, in *Rhododendron*, the percentage take may be high but subsequent survival was significantly influenced by cutting size.

Stock plant pruning

Although there was some variation between species and years, several trends were identified when attempting to optimise rooting and cutting survival. With the exception of *Acer*, harder pruning of stock material generally led to more vigorous shoot growth and the production of cuttings with greater survival potential.

Table 25. The effects of stock plant pruning regimes on rooting and winter survival of cuttings

Species and pruning regime	Percentage rooting	Percentage survival
Acer palmatum 'Bloodgood'		
Hard pruning	64	19
Light pruning	94	56
Corylopsis pauciflora		
Hard pruning	95	43
Light pruning	86	13

Type and size of cutting

Thin stemmed cuttings often rooted well but failed to survive overwinter, in contrast, winter survival of thicker stemmed subjects such as *Cotinus, Magnolia* and *Viburnum* was largely unaffected by cutting size and stem diameter.

For several thin stemmed species, including *Acer, Corylopsis* and *Rhododendron*, taking larger or thicker cuttings often improved rooting and winter survival, most probably on account of their greater carbohydrate content. In practice, however, a balance needs to be struck between optimising cutting size and a later or delayed harvesting time. Such a delay can reduce rooting and survival; larger cuttings rooted later in the season may not root as well as those collected earlier. Later collected cuttings are also often less active physiologically and very large cuttings can easily stress in suboptimal propagation environments.

Part of the stock plant from which cuttings are taken

In early trials, there were interactions between the propagation environment and the part of the stock plant from which cuttings were removed; in the case of *Rhododendron*, the greatest failure occurred among those cuttings taken from the base of the stock plant.

Handling of cuttings

The way cuttings are handled and stored between collection and insertion can also reduce subsequent survival, especially in the case of soft, summer cuttings which are not kept cool, shaded and fresh. In HNS 84, with *Magnolia,* for example, the winter survival of cuttings was reduced by storing them under polythene covers in ambient conditions for 24 hours prior to sticking (even though root initiation was unaffected) compared to cold storing them (for 48 hours), which was not detrimental to subsequent survival or development.

Overwintering environment

Overwintering environments were found to affect the survival of rooted cuttings of many species. In some subjects, most notably *Acer palmatum* 'Bloodgood' and *Rhododendron*, overwintering in a non-ventilated polythene tunnel reduced survival compared to a well-ventilated structure, due largely to the greater humidity of the latter. In general, polythene tunnels should be well ventilated throughout the winter as conditions allow.

The use of cold storage facilities appeared a feasible and more effective technique (compared to tunnel environments) to ensure good survival rates for some species, notably *Ceanothus, Corylopsis, Magnolia* and for some cutting types, *Rhododendron*. However, care is required to ensure successful transition back to ambient conditions, most significantly avoiding excessive exposure to high temperatures and high light levels.

Cuttings of *Ceanothus* and *Corylopsis* were also susceptible to winter losses due to irregular or infrequent watering in some of the environments, underlining the need to ensure that cells do not dry out during winter.

Winter protection

The project also confirmed that polypropylene fleeces and 'bubble' sheets are useful in providing extra additional frost protection during short-term, radiation frosts; temperatures under such covers were often 3–4°C higher than those recorded outside.

Using lighting to improve survivability

There are often situations where timely propagation and liner potting is not possible and using photoperiodic lighting to promote vegetative growth (thereby enhancing winter survival and giving stronger plants the following spring) may be advantageous.

In a study on the overwintering of a range of HNS species (Loach and Whalley, 1975), long day lighting was compared with unlit treatments, gibberellic acid spray treatments (a naturally occurring plant hormone associated with growth promotion) and extended photoperiods with carbon dioxide (at three times atmospheric concentration). While some species, such as *Acer saccharinum*, responded identically to light and giberellic acid (which substitutes for long days), others were far more responsive to light than giberellic acid, for example *Betula pendula*, where light, and light plus carbon dioxide gave greatest growth and a marked increase in percentage survival (Table 26).

Table 26. Percentage survival and fresh weight in *Betula pendula* 12 months after cuttings were taken (Loach and Whalley, 1975)

Treatment	Percentage survival	Fresh weight/plant (g)	
		Shoot	Roots
Control	16	61	33
Giberellic acid, 100 ppm, weekly	21	71	46
Extended photoperiod	62	80	42
Extended photoperiod + carbon dioxide	70	90	44

While lighting may reduce growth the following season, where such high percentage winter survival rates as this are achieved, lighting may have a useful role to play in improving winter survival of rooted cuttings and liners.

Using long days (night-break lighting) to delay defoliation and the onset of dormancy and so increase food reserves may assist winter survival although responses to photoperiod differ widely between species. Some species are known to be responsive in that the onset of dormancy is prevented or delayed by short night-break lighting treatments (detailed by Vince-Prue, 1975) and so the overwintering survival of such subjects may be improved by using this technique. Such species include *Acer ginnala, Acer palmatum, Betula lutea, Betula pubescens, Cercidiphyllum japonicum, Diospyros virginiana, Hibiscus syriacus, Pinus taeda, Pinus ponderosa, Platanus occidentalis, Populus tacamahaca, Pseudotsuga taxifolia, Rhus typhina, Taxus cuspidata, Tsuga canadensis* and *Weigela florida.*

There are some HNS subjects where this type of treatment is detrimental; night-break lighting was shown to be a cause of death in trees where continued growth prevented wood from maturing (Kramer, 1937). Similar results have been observed with shrubby HNS species, notably *Cotoneaster dammeri* 'Skogholm'.

Aspects of liner production

Often, propagation and liner production are managed as separate entities yet they are very much interrelated and should be integrated as much as possible for best results. What happens at the first stage has consequences on the next stage. The use of good quality cutting material, for example, and its management during and following rooting strongly influences liner quality and business profitability.

Managing rooted cuttings for quality liner production

AHDB Horticulture project HNS 27: ***Propagation: stock plant and cutting processes influencing subsequent plant quality***, aimed to develop guidelines for the management of rooted cuttings, which enabled growers to increase profitability by improving liner quality and shortening production times. The work established some important guiding principles for the successful transition of newly rooted cuttings to a quality liner and on to a finished plant. While the studies focused on *Cotinus*, comparisons were made with other HNS species (such as *Acer palmatum* 'Aureum') to provide a useful and broader contrast.

Propagation should be done as early as possible in the season to enable strong root systems to develop prior to winter. Extending the growing season under glass (and the use of supplementary lighting) to delay dormancy and defoliation, and so help increase overwintering food reserves, may compensate for late propagation to an extent and aid overwintering.

When preparing cuttings. Retaining as many of the original leaves as possible and restricting any initial plant shaping to a prompt pinching of new shoots, rather than harder pruning prior to winter, will also improve survival rates.

Very supportive rooting environments, such as fog or closed mist, for example, should be used where necessary to achieve good rooting as this will help reduce weaning losses due to quicker and better root development. Weaning should also be rapid but progressive, for example, a short period of high humidity without leaf wetting, under a polythene tent, so that normal growth is resumed as quickly as possible while minimising losses.

Several important principles emerged from HNS 27 that can be used to guide nursery practice for the successful transition of newly rooted cuttings to liners with many difficult subjects. These include:

- Propagation environment: use of a highly supportive rooting environment such as wet fog or closed mist, particularly for softwood cuttings taken early in the season, helps to promote strong and rapid root development
- Leaves on cuttings: retaining the original leaves on cuttings, where practical, assists the survival and establishment of cuttings. Even those leaves that appear to be in poor condition following a lengthy period of wetting during rooting are usually able to photosynthesise. This also saves preparation time and many HNS subjects root well without the need to remove leaves
- Shoot growth: rooted material should be weaned in a timely and progressive manner. New shoots that develop during rooting and weaning often fail to survive and so are of minimal value yet are net consumers of food reserves; rapid weaning helps to minimise this problem

- Root disturbance: root disturbance should be kept to a minimum, ideally using plug trays to root cuttings or direct sticking where space allows. Where material is rooted in standard trays (and so more liable to root check), ensure it is thoroughly weaned well in advance of final transfer to the growing on environment in order to reduce water stress
- Weaning environments: in general, high humidity environments with limited shade achieve higher survival rates than drier environments with extra shade, although temperatures should not be so high that they encourage soft new growth. Use mist (or a polythene/fleece tent) for weaning but ensure the mist is well controlled and gradually reduced to enable a smooth transition from the higher humidity rooting environment
- Time frames: the time frames allowed for rooting and weaning are important, in general, it is better to extend the rooting period to achieve good root development and then restrict the weaning period (to about 7–10 days). With subjects whose leaves usually deteriorate before full rooting is achieved (such as *Acer palmatum, Cotinus, Euphorbia, Lavandula, Rosmarinus* and *Senecio*), aim for an earlier transition to a drier but still supportive environment
- Spacing during establishment: rooted cuttings should not become overcrowded once they resume growth because the accumulation of food reserves and development of well-spaced branches is essential and depends on adequate illumination of all leaves. Therefore, ensure rooted material is adequately spaced
- Pruning: for many HNS subjects, pruning is essential to create the best possible shape but ill-timed or over zealous pruning can be counter-productive and jeopardise winter survival when done in the extreme on certain subjects. As a general guide, rooted cuttings of less vigorous subjects (including *Cotinus, Corylus, Magnolia, Rhododendron* (some) and *Syringa*) should be allowed to grow reasonably freely during the first year to enable food reserves to be accumulated in the form of strong stems and root systems, which aid overwintering survival and provide a sound basis for pruning early in the second year. However, many quick growing HNS species do respond positively to summer pinching or trimming (including *Choisya, Ceanothus, Forsythia, Hydrangea, Hypericum, Lonicera nitida, Philadelphus, Photinia, Senecio, Spiraea* and *Weigela*)
- Propagation timing; in HNS 27, plant quality after one year in a container correlated better with stem diameter than any other measure of liner quality, underlining the need for early propagation and to build up food reserves post-rooting. Although many HNS subjects can be readily rooted throughout the late spring to summer period, early insertion and rooting gives a clear benefit in terms of liner quality as it provides the longest possible time frame for rooted cuttings to accumulate food reserves

The disadvantage of late propagation (it is often unavoidable) can be partly mitigated by using heated glass and supplementary lighting to extend the growing season, although this is only likely to be economic for high value subjects and it can be difficult to harden off such material, necessitating the provision of some degree of winter protection.

Managing disease incidence on overwintered HNS liners

High relative humidity is common in unheated polythene tunnels during the winter period and this can produce environments conducive to the development of leaf diseases such as *Botrytis* and downy mildew. AHDB Horticulture project HNS 49/49a: ***Influence of humidity and other stress factors on plant growth***, underlined the importance of maintaining good environmental control with protected HNS, particularly within polythene tunnels and especially for crops susceptible to leaf diseases like *Botrytis* and downy mildew.

The work highlighted the need to combine good cultural management, such as growing on low level irrigated sand beds rather than overhead irrigated gravel beds, with effective, balanced fungicide programmes started early in the life of the crop, in order to produce top quality plants. Keeping relative humidity in tunnel crops below 80% reduced levels of diseases favoured by high humidity.

Capillary sand beds improve liner quality by keeping foliage dry and clean, so reducing disease incidence

Crops should be ventilated as conditions allow, even in winter, to boost the air movement around liner crops and susceptible crops should not be irrigated overnight when foliage will take longer to dry, so exacerbating disease risks. Crops should also be spaced as they develop to enable good air movement between plants, so helping to dry foliage and reduce disease incidence.

Integrating propagation and liner production – the 'designer liner' concept

In nursery situations, it is far better to combine propagation with liner production and manage them together rather than separately to achieve quality production in a cost-effective manner and with minimum waste.

AHDB Horticulture project HNS 69: ***Ornamental shrubs: Developing the concept of the 'designer liner'***, aimed to develop a more integrated approach to growing liners, establishing the requirements for shape and size at the start and refining the production process to achieve this efficiently and effectively. This is the essential principle of the 'designer liner'.

The work investigated the effects of stock plant pruning, use of pre-branched cuttings, the size and spacing of cuttings, the rooting environment, pot size, nutrition during rooting and establishment, and pruning or pinching following rooting, using a small number of HNS species representing different plant types. The evaluation of pre-branched cuttings was based on the view that they are more able to develop and support new laterals than young, rooted cuttings.

For many of the species tested (including *Cotinus, Forsythia, Garrya, Magnolia* and *Photinia*) the use of pre-branched cuttings enabled the rapid production of an established quality liner compared to liners derived from apical stem cuttings. In some of the treatments, rooting a large pre-branched cutting resulted in the formation of an almost 'instant' liner, ready for potting into a 2 or 3-litre pot as soon as it had been weaned. Larger cuttings were no more difficult to root (provided they were placed in a supportive environment) and rooting in some species, such as *Cotinus,* occurred faster when there were a number of actively growing shoots present on the cutting.

The use of pre-branched cuttings with subjects such as *Photinia* enable the rapid production of established, quality liners

The ability to form pre-branched cuttings on stock plant hedges will vary with species (*Syringa,* for example, is less productive in this respect). The optimum environment for rooted pre-branched cuttings will also vary with species. For example, a high humidity fog system will be necessary to support cuttings of relatively difficult-to-root species such as *Cotinus* and *Magnolia* but large (20–25 cm high) pre-branched cuttings of *Forsythia* and *Weigela* should root readily under a lower humidity mist.

The best results in HNS 69 were generally associated with direct sticking cuttings into 9 cm or 1-litre pots, although it was feasible to produce the easier subjects in plug trays. The advantage associated with pots related to keeping the cuttings stable during propagation rather than a requirement for more space. For example, results with *Cotinus* suggest that spacing during propagation and overwintering had little impact on subsequent growth and pre-branched cuttings could be produced at the same spacing as direct stuck conventional cuttings.

Although the most impressive results in this work were often associated with pre-branched cuttings, quality liners could also be obtained from conventional apical cuttings by optimising other factors, such as enhancing the nutrient status within cuttings as early as possible. The addition of nutrition to *Magnolia* cuttings early in the production cycle enhanced growth and lateral formation.

In a number of cases, when plants were being propagated by conventional apical cuttings, it was found that a single pruning treatment implemented shortly after bud-break in the second year was as effective or more so, than earlier pruning or pinching. Good plant size and shape were obtained in *Magnolia* and *Photinia* by single pruning treatments in March, following bud break.

International Plant Propagators' Society

The International Plant Propagators' Society (IPPS) is an international association of plant production professionals whose primary mission is to advance the art and science of growing plants and to disseminate knowledge throughout the global community from and to those engaged in plant production for the benefit of all.

Membership includes those with an interest in ornamental horticulture, vegetable and fruit plant production, floriculture, silviculture, plantation crop production, amenity horticulture and all other fields related to the production of plants for public use.

The mission of IPPS, with a focus on the global community of those involved in horticultural plant production, is to:

- Share knowledge, information and skills
- Provide guidance and support for lifelong career achievements
- Increase recognition of the profession
- Maximise the integration of research, education and horticultural knowledge

For further information, visit **ipps.org**

The following five papers are reproduced courtesy of the IPPS from various proceedings and publications over several years.

Cracking *Photinia*

Geoff De La Cour-Baker, Manager, Palmstead Nurseries Ltd

Achieving commercially viable rooting of *Photinia* 'Red Robin' cuttings had always been a problem for us and, so far as we could see at the time (2006), no real trials had been attempted with this subject.

We decided therefore that it would be a worthwhile and enjoyable IPPS project, to explore ways of getting our *Photinia* cuttings to root better. It was also hoped that the project would broaden our propagation knowledge and understanding, and act as an introduction to the use of rooting hormones.

To begin with, we needed to understand the propagation problems being experienced, including rotting and excessive callus formation, in order to find a solution. Our efforts, therefore, focused on finding the optimum type of cutting, rooting environment, hormone treatment (if required) and time of year for propagation. We also bench grafted several plants in winter to see if this was a better approach.

Through our experience with rooting other subjects, we decided that nodal tip cuttings (8 cm in length, no wounding) would be the best starting point. We then explored taking different types of cutting material at various stages of the year: softwood (red tipped) in May, greenwood/semi-ripe (red stem) in August and November and evergreen hardwood cuttings during February.

In all cases, the leaves of the cuttings were reduced to prevent overlap within the trays and the cuttings were inserted into a peat-based rooting medium. No rooting hormones were used in this initial study. The trays were then placed in three different rooting environments: a fogging unit, a mist bed and under contact polythene. Base heat (18–21°C) was used between November and April. Each trial consisted of four x 54 plug trays. Cuttings were then monitored for signs of callus formation, rooting, leaf-drop, rotting off and general health status. The results from the first trial (cuttings and rooting environments) were disappointing and are presented in Figure 8.

Following this initial study, we turned our attention to the use of rooting hormones in an attempt to increase the rooting percentage. The hormones we selected were based purely on availability and recommendation, as were the strengths at which we mixed and applied them. We also tested one theory of using an aspirin solution to root cuttings.

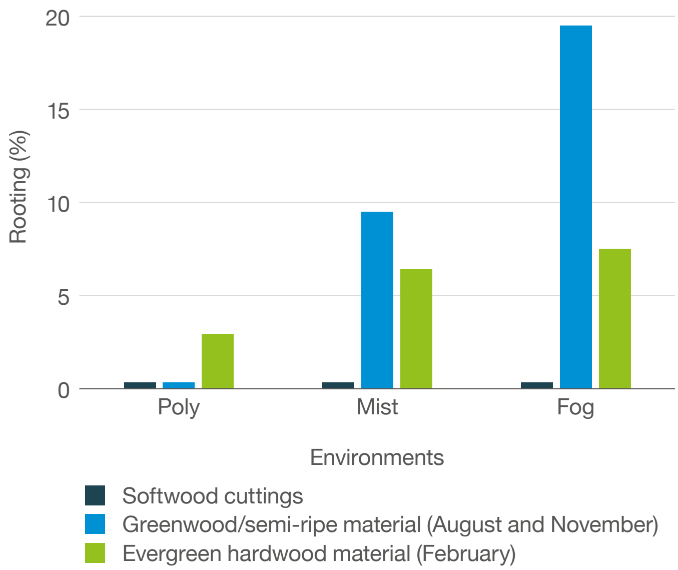


Figure 8. *Photinia*: types of cuttings and different rooting environments

The hormone trials took place in November using semi-ripe cuttings (no wounding) under fog with base heat (18–21°C) and these produced noticeably better results by February of the next year. The treatments used were: Synergol (liquid 'quick dip' at 5,000 ppm and 3,000 ppm IBA), Seradix 3 (talc at 8,000 ppm IBA) combined with liquid acetone and an aspirin solution (four tablets x 300 mg to 200 ml of water). With the Seradix treatment, the cuttings were first dipped into the acetone for three seconds and then the hormone powder, the idea being to use the acetone to 'extract' the IBA within the hormone powder and improve absorption of the hormone by the cutting.

The application of rooting hormones dramatically increased rooting percentage, most notably the Seradix 3 + acetone dip. The results are summarised in Figure 9.

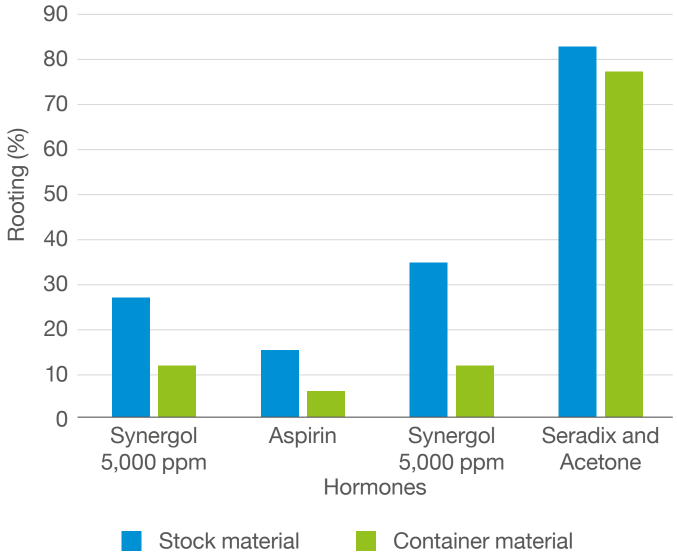


Figure 9. *Photinia*: Comparison of different rooting hormone treatments

In the Figure 9, key stock material refers to cuttings taken from field-grown stock plants and container material was that taken from container-grown mother plants. All treatments were applied as five-second 'quick dips' to the base of cuttings (except Seradix 3, where cutting bases were dipped in acetone for three seconds and then the powder).

We used the results from the hormone trial and applied its principle to a large batch of *Photinia*, taking cuttings from stock in August and October and successfully produced rooting percentages of 92%, a major improvement on the original trial. These plants were strong and healthy with good root systems and, after a short period, were potted on into the liner stage. The nursery requires over 10,000 rooted cuttings of *Photinia* 'Red Robin' a year, so our trial results were a great success for us and a real breakthrough for the nursery.

As a comparison with cuttings, we also side grafted scion material of *Photinia* 'Red Robin' onto *Photinia davidiana* rootstocks (2-litre pots) during February. However, the results were disappointing and, for us, this approach was not a cost-effective or time-saving means of producing large batches of *Photinia* 'Red Robin' (although the small number of successful grafts did grow on to make good healthy plants).

Hibiscus grafting

Mark Howard, Nursery Supervisor, John Woods Nurseries Ltd

Hibiscus syriacus cultivars can be propagated by cuttings or grafting. Grafting produces a much stronger, saleable plant in less time than traditional cuttings and, because the wood of *Hibiscus* is quite soft, they are relatively easy to graft. They are a good plant for anybody new to grafting to practice on with a reasonable level of success. Here is how to do it.

- Graft in the dormant season, usually January or February
- Use one-year-old *Hibiscus syriacus* seedlings that are approximately 8–10 mm in stem diameter
- Scion wood can come from specially grown stock plants that need to be cut back hard in the spring to give strong healthy one-year-old material for grafting the following winter. Alternatively, scion wood can come from plants grown in production that need pruning back. Collect material that is at least 4–6 mm in diameter and is firm, so that it doesn't bend too easily
- Prepare the scions as you would a hardwood cutting with a sloping cut at the top just above a bud and approximately 15–18 cm in length. There is no need for a bud at the bottom. Place them in a sealed polythene bag in the cool until required for grafting
- Prepare the rootstocks by trimming the roots and removing all the top growth just above the hypocotyl, (this is the area just above where the roots start to grow and the area where you will make the rootstock incision). Clean this area to remove any soil and avoid the risk of contamination. Grafting low down like this will reduce suckering
- There are three types of graft that can be used depending on the size of the scion. If the rootstock and scion are of similar thickness, then a straightforward whip graft can be used. If, as is usually the case, the scions are smaller than the rootstock then you can use a side graft, matching the cambiums accordingly. As the cambial layer is sometimes quite deep in a *Hibiscus,* often the most suitable graft to use is a rind graft. This ensures good cambial contact without having to cut too deeply to expose the cambium, as with a side graft

Grafting produces a much stronger, saleable plant in less time than cuttings

- Use 150 mm by 3 mm white flexi-bands (biodegradable rubber) for tying the graft together, these will degrade sooner than other types and won't cut into the softwood
- Dip the whole graft into grafting wax at a temperature of 70°C, thereby sealing everything except the roots
- Plunge the grafts into deep black crates filled with a general potting medium, ensuring the roots are covered but not the scions and place these crates in an environment that gives an air temperature range of 5–15°C
- Callusing and subsequent top growth will take place within four to six weeks, at which point they can be moved to cooler, frost-free conditions. Once top growth has started, then the grafts will need lining out or potting up
- Good, strong, well-shaped plants will come from those that are planted in well-drained open ground for a period of one to two years
- Run a hedge trimmer over them regularly when the growth is soft to encourage prolific branching
- The main pest to watch out for is aphid, otherwise *Hibiscus* are relatively pest and disease free. Yellow growth in the spring is usually only temporary and invariably due to cool nights while the tops are actively growing but the roots are not yet in full growth. Foliar feeding will help, especially in container-grown crops

Lavender propagation – rooting rotters

David Hide, Technical Manager, Walberton Nursery

Lavandula can be propagated from seed, cuttings and layering but when large batches of identical plants of a named cultivar are required, cuttings are the most common method. However, they are as easy to rot as they are to root! Here is a brief overview of how to propagate them from softwood and semi-ripe cuttings, based on our experiences of raising young plants here at Walberton Nursery.

Softwood cuttings

At Walberton, we root up to 100,000 softwood tip cuttings each year between January and June.

- Uniform cuttings are taken from purpose grown one-year-old 3-litre stock plants under (frost) protection. These yield between 50–100 cuttings every four to six weeks, once the first flush of growth has been cut, which is usually in March and April
- Cutting length varies and is both species and cultivar dependent; *Lavandula dentata* 'Dusky Maiden' may be 6 cm, while *Lavandula angustifolia* 'Hidcote' may only be 3 cm in length
- Consider cleaning up stock via micropropagation to retain vigour. This is something we do every four years for many of our lavenders

Stock plants are grown to provide the nursery with timely supplies of high-quality, uniform cuttings in the required quantities

- All cuttings are internodal tips and all preparation is done at collection, using 'snips' (small scissors) to make a clean cut just above a node. This produces a bare section of stem that is inserted up to the next pair of leaves

Internodal softwood tip cuttings are rooted using dibbled Preforma trays

- By separating the collecting from the sticking we are able to monitor each part of the operation. We feel this allows us to develop more focus to each operation and has helped, in particular, to increase our sticking rates, which in 2012 averaged 500 cuttings per person per hour. We only make tip cuttings because, although stem sections root okay, they also rot more easily and sometimes fail to grow away, even if they are well rooted
- No further preparation is required or rooting hormone used

- We insert all of our lavenders into Preforma Jiffy 126s (ready-to-use plug trays), which are centrally dibbled. This provides us with something to 'aim at' and so removes any indecision at point of insertion (which also speeds up the sticking process). Softwood tip cuttings are easier to insert into a dibbled tray and so there is less bruising of the soft stem, with a resultant reduction of *Botrytis* entering at this point. This had been a major cause of losses prior to us using dibbled trays
- All rooting takes place under milky Thermaprop polythene film tents, with a basal heat of 20°C
- Rooting takes between 14–21 days but it will be a further seven days before the cuttings are fully weaned
- We would expect rooting percentages to be in the high nineties

Cuttings are rooted (14–21 days) under polythene with base heat (20°C) then weaned (seven days)

Semi-ripe cuttings

- Select 6–8 cm long semi-ripe cuttings from non-flowering shoots in August and September
- Insert into a free draining propagation medium and place in a low humidity rooting environment such as a cloche or unheated polythene tent
- Rooting will take place within eight weeks

This technique was for a long time the industry standard but has since been superseded by the use of softwood cuttings.

Key elements to success with lavenders

- Have access to good quality stock and understand the rooting requirements of a lavender
- Softwood tip cuttings root quickly in high humidity environments but the Thermaprop polythene reduces foliage moisture, which lavender dislikes. Very little condensation forms on the polythene, thus reducing the risk of drips, foliage wetting and *Botrytis*. Lavender is very prone to fungal diseases and resent sitting for too long with wet foliage or waterlogged root zones and is the reason why we use both Thermaprop polythene and Preforma plugs
- Monitor the crop daily and react to the changing weather to maintain the optimum rooting environment
- Water in the morning only and on dull days, consider venting the ends of tunnels even before rooting has commenced. This will reduce the time that the cuttings sit with wet foliage
- We apply a weekly fungicide programme; I'm not sure this is entirely necessary but we do it for good measure
- Once rooting commences, reduce humidity levels by first opening the end of the tunnels. Replace with a fleece tent within a week to complete the weaning process
- Softwood tip cuttings grow away quickly and it is possible to assess when the rooting and weaning processes are complete, as cuttings that still require higher humidity environments will quickly wilt if left unprotected
- Don't be afraid to re-cover with fleece or polythene at this point

Well-rooted cuttings, fully weaned and ready for potting

Rhododendron and *Azalea* propagation at Millais Nurseries

David Millais, Millais Nurseries

Millais Nurseries is a specialist *Rhododendron* nursery producing about 35,000 plants per year for sale throughout Europe to private gardeners, parks, landscapers and garden centres. Sizes range from dwarfs in 3-litre pots up to specimens in 150-litre pots. We have one of the largest ranges in the world, growing more than 800 different varieties but rarer varieties are only propagated every two to three years to simplify production.

- Propagation methods: our main propagation method is by cuttings but we make use of autumn grafting for difficult-to-root subjects and seed for some of the wild collected species. We also buy micropropagated liners of other difficult-to-root types of *Rhododendron* but our experience has shown that they do not always make successful plants. Micropropagation is very successful with some varieties but on others such as *Rhododendron* 'Crest', characteristics such as flower size, colour or habit can be altered from the original clone. Frustratingly, we have also experienced weak plants that snap off at the base after three years due to tweezer damage while handling the cotyledon in the laboratory
- Facilities: our propagation glasshouse has aluminium roller benches with Thermabed hot water heating. Each bench has individual controls for temperature and mist, allowing flexibility and enabling heat savings to be made. With slow-rooting subjects such as *Rhododendron*, the ability to pick over the crop at waist height has proved invaluable over the years The benches are covered with capillary matting and to aid drainage we have small 'tails' of matting dropping below the benches, which help to suck out excess moisture. On top of the matting, we have perforated black polythene that is easy to brush down and keep clean. The benches have metal hoops over the top, which support the mist lines and create a polythene tent to give good humidity. At least once per year we strip out all the mist nozzles, filters and anti-drip valves and soak them in vinegar overnight to remove limescale deposits. The benches and capillary matting are cleaned using Jet 5 and all the automatic controls are checked for operation

Azalea and *Rhododendron* cuttings are rooted under polythene with mist and base heat during the spring and summer periods

- Timing: our cuttings season starts in late May with deciduous *Azalea*. We find that most of these will root quite easily but we still have difficulties keeping them alive through the winter and making them break into growth in spring. Our objective is to root them as early as possible so that we have a large well-rooted plug in time for winter. We have tried keeping them cold to preserve sugar levels during the winter and keeping them growing and warm for longer in the winter but we still suffer losses during the first winter or two
- Our cuttings season then moves onto *Rhododendron* species, which we like to take by early July, followed by compact species, *Rhododendron yakushimanum*, dwarfs and evergreen *Azalea* types. Recently, we have been shifting hybrid propagation from autumn to early summer with good results but they do take up a lot of space on the benches. Due to poor results with cuttings taken in the really hot weather of August, we try to take them either before or after any heatwave. Rooting can be as short as four weeks for *Azalea* and as long as six months for difficult types of *Rhododendron*
- Stock plants and collecting cuttings: we like to collect cutting material fresh from our own stock plants where possible but we also make use of prunings from our liner crop. We try to collect early in the morning when the cuttings are more turgid but have found that turgidity can be increased by refrigerating in a moist polythene bag overnight if needed
- Leaf trimming of cuttings: many people advise against trimming leaves due to the risk of disease entry through the wound but we have always found it beneficial in reducing transpiration and preventing disease spread through overlapping wet leaves in |the tray. On small leaved *Rhododendron* we do not trim but on hybrids with leaves more than 50 mm long we, typically, reduce the size of the leaf by half. Since rhododendrons do not like to be disturbed at potting time, we root in cells of either 40 mm or 50 mm depending upon subject. The growing medium used is Baltic peat with good aeration and drainage and we normally set the base temperature at 17°C
- Wounding and rooting hormones: dwarf *Rhododendron* and *Azalea* are quite easy to root and these are normally done without any wounding at the base but on hybrid rhododendrons we usually wound the bottom 15 mm of stem down to the cambium layer to aid uptake of hormone. Historically, we've mainly used a powder formulation (0.3% IBA) but sometimes switched to a weaker concentration early in the season or on white flowered *Azalea* cultivars, which are prone to scorch. Later in the season, harder cuttings and more difficult rooting plants sometimes need stronger hormones but there is a fine line between a beneficial hormone and one that scorches the cutting. We found liquid hormones (such as Synergol when it was available) allowed greater fine-tuning of strength and we are currently building experience with the new hormone products available to us

- Rooting environment: during the summer months, we typically use mist underneath closed 'milky' white thin grade polythene plus additional shading on the outside of the glasshouse. In addition to the regular wet leaf mist, we have added a time clock for restricting the mist in the morning and evening turning it off at night to try to keep the cuttings drier. Following the success of AHDB Horticulture trials, we are currently trying out Evaposensor controls, again to reduce water application. During September, we restrict the mist still further and aim to turn it off completely by the end of the month. By then, light levels and temperatures are falling and we can maintain good humidity by just relying on closed clear polythene through the winter and the occasional burst of mist. During the winter, we typically vent each tent for an hour or so, two to three times per week
- Crop protection: during propagation we do not use many fungicides on the cuttings but regularly spray over with compost tea and products such as Revive, SB Plant Invigorator and seaweed feeds
- Records: we have the benefit of my father's propagation records going back more than 30 years showing timings and hormone used for each variety. However, as each season is different the records can only be a guide so we use experience to tell us when a shoot is ripe for taking
- New ideas: propagation is a long learning curve and organisations such as the IPPS help spread knowledge. Sometimes, a visit to another nursery gives you an idea to try, which may or may not help your situation. Every propagation house is different and our worst year for cutting success was when we built our new house and everything changed! It is worth trying new techniques but don't change too much at once

Success with *Hebe* cuttings

Karl O'Neill, Propagation Manager, Bransford Webbs Plant Company

At Bransford Webbs, we grow approximately 180,000 *Hebe* plants, the vast majority of these being the compact, small leaf varieties such as 'Pink Pixie', 'Margret' and 'Pascal' that we supply to garden centres in the spring. We grow a limited number of the larger leaf varieties, which are propagated in a very similar way but with a longer production cycle. Our aim is to produce a clean, compact, well-branched 2-litre plant for market from February onwards.

One of the major factors in successful *Hebe* propagation is the quality of the stock plants and, in turn, the cutting material they produce. *Hebe* is relatively easy to root, however, the juvenility and cleanliness of the stock material will dictate the quality and vigour of the rooted cutting. Juvenile, current season's growth will root readily and grow away vigorously, enabling early trimming opportunities and so a well-branched plant.

None of our cutting material is taken from traditionally grown stock plants as we feel this is not ideal for *Hebe*, which is susceptible to a number of foliar diseases and needs to be kept young and actively growing. Instead, we grow all our stock plants alongside the current season's saleable crop, meaning that they receive the same (ideal) cultural and fungicidal treatments, which help produce the clean, juvenile growth we require. In fact, the stock plants are used once and then destroyed or grown on to make a later saleable batch.

Cuttings are taken in the autumn from stock plants that have been potted three months previous and have had their first flush of juvenile growth. Stem tip cuttings are taken approximately 20–40 mm long, with the leaves removed from the lower half. No rooting hormone is used, as this is not necessary when rooting *Hebe*; it also adds labour and chemical costs and has been shown to damage some varieties.

Plug for liner potting

The cuttings are struck in a preformed plug media, containing a peat, perlite, bark and vermiculite mix, with added coir (20%) for structure and drainage over the winter months. The media contains both base and controlled release fertilisers. A mist system with base heat (18°C) and automatic shading is used to root the cuttings. The rooting environment is computer controlled and is governed by a solar radiation sensor and thermostatic probes.

The majority of the varieties root in two to three weeks, with the mist being reduced by approximately half after the second week and then reduced further each week until rooted. They are then weaned in situ for one to two weeks and moved out into a colder (frost-free) and less humid environment to harden off. This also helps to slow down the soft flush of growth they put on in the rooting environment.

The rooted cuttings are overwintered in a cold glasshouse, where they continue to grow slowly but can extend to 60–80 mm. In late winter, they are machine-trimmed to approximately 20 mm to encourage breaks. Then, six to ten weeks after trimming, they are potted on into a 9 cm liner pot and grown on sand beds. They are then potted into their saleable 2-litre pots five to six months later.

Attention to detail and good cultural practice produces uniform batches of clean looking good stock ready for sale

All the way through the production cycle, our *Hebe* crops are subjected to a rigorous fungicide programme, protecting against downy mildew, powdery mildew, leaf-spots, *Botrytis* and *Fusarium*. With an evergreen crop like *Hebe*, prevention is definitely better than cure.

Research and knowledge transfer requirements

Propagation management

This section summarises the current knowledge gaps in the propagation process and suggests appropriate research or knowledge transfer to address them.

Stock plant and cutting nutrition

Little detailed work appears to have been done or, at least published, on the nutritional requirements of stock plants to sustain their production of uniform, high-quality propagation material or on the effects conferred by supplementary feeding stock plants on the subsequent rooting potential of cuttings. Research is needed to address this, examining the use of liquid and foliar feeds, compost teas, etc.

Cold storage of leafy cuttings

While the AHDB Horticulture grower guide ***HNS Cold storage – How to successfully cold store hardy nursery stock***, helped address current knowledge gaps on how to get the best from cold storage, research is needed to provide a better understanding of the cold storage requirements of leafy cuttings and, in turn, enable the development of more specific guidelines for optimum storage times, temperatures and conditions for a range of HNS subjects.

Such information would help enable growers to cold store cuttings to optimum effect and further exploit the benefits of controlled temperature storage as a propagation management and scheduling tool. The use of cool boxes to remove 'field heat' when collecting soft and semi-ripe cuttings should also be considered as a simple and cheap means of maintaining freshness before propagation of small quantities of material.

Lean management and its application to propagation work

Lean management is a set of techniques that can be used to help reduce costs and add value to businesses. It can do this by improving productivity, reducing plant losses and removing wastage.

Some propagators appear unaware of the wider benefits of lean and how its principles and practices can be applied to HNS propagation. Knowledge transfer tailored to the needs of propagators would be useful to build confidence and raise awareness of the considerable savings that may accrue from the use of lean management in the propagation process.

Wounding of cuttings

Wounding cuttings increases the quantity and quality of roots as new sites for root initiation are triggered when basal stem tissue is exposed. It is a particularly useful technique to coax roots from difficult or slow-rooting subjects, especially where the wood is quite lignified. Much of the current knowledge base is not research-based. New work should consider and trial different methods of wounding, linked with the use of hormone rooting aids.

Leaf removal from cuttings

Avoiding the need to remove or strip leaves from large numbers of cuttings saves considerable time. Past research to investigate leaf removal with a range of species found that many woody HNS subjects rooted better when their lower leaves were retained (although *Hebe* cuttings rooted better following leaf removal). While this work highlighted scope for considerable time and so cost savings for growers by not removing leaves, further trials work with a wider range of woody and herbaceous subjects is required to substantiate its initial findings before firm recommendations can be made.

Rooting hormones

Following the commercial withdrawal of Seradix products and Synergol during 2011, the Dutch product Rhizopon (based on IBA and available as ready-to-use powders or water soluble tablets dissolved for use as dips or sprays) is now the standard product approved for use and a useful rooting guide to accompany the product range is available to growers.

While 'quick dip' rather than powder applications have been shown to improve rooting in some difficult HNS species, growers no longer have easy access to the higher strengths required to achieve high rooting.

Currently, there are no approved liquid rooting hormones available for sale to the UK market containing high concentrations of IBA. The only product containing IBA that can be dissolved in water is the Rhizopon AA 50 mg water soluble tablet and the maximum concentration approved is 1,500 ppm. New research to evaluate different hormones, formulations, timings, combinations and rates for a range of HNS subjects would help growers optimise their use and identify current product gaps.

Propagation techniques

Improving propagation of difficult-to-root subjects

While the main propagation techniques are well understood, there is scope for new research to help improve the propagation and economic production of difficult-to-root subjects (such as varieties of *Camellia*, *Daphne, Rhododendron* and various herbaceous perennials including *Acanthus, Euphorbia* and *Romneya*), which would enable best practice guidelines to be developed for growers. New work should include stock plant management, propagation timing, seed treatments, rooting cuttings, peat-free rooting media, new rooting hormones, wounding techniques and rooting environments.

Physiology of rooting

There is a need for new work on plant physiology during propagation, to develop a better understanding of why some plants propagate more readily from certain types of cuttings than others and at a particular time of year.

Why, for example, are some HNS subjects slower or more difficult to root than others? What are the 'triggers' or rooting co-factors involved? Such work would have significant commercial value, were it to create easier and more timely rooting protocols for difficult to propagate subjects while delivering more flexible propagation periods for other, easier-to-root plants.

New work should also investigate the vegetative versus floral dichotomy within herbaceous subjects to help enable optimum timings to be established for successful rooting.

Preconditioning cutting material

New work on preconditioning stock plants should specifically cover the use of darkness to stimulate rooting of difficult subjects and the use of artificial lighting during propagation to build on earlier work aimed at improving the rooting ability of cuttings.

The benefits of preconditioning shoots prior to collecting cuttings of difficult-to-root subjects were highlighted by the work at NIAB EMR but this hasn't progressed beyond the research stage, perhaps due to practical complications. However, with more stock plants now grown in containers, often under protection and so with greater environmental control, the process should be much easier and simpler to mechanise and manage.

There may also be a wider role for artificial lighting to improve the yield and timeliness of cutting production from container-grown stock plants to aid propagation scheduling and the rooting of cuttings post-insertion.

Lighting can be used with success commercially to improve winter rooting of herbaceous perennials and secure early cuttings from stock plants under protection. While the conclusions of previous work were that lighting (particularly post-insertion) was unlikely to be economic, it may now be timely to undertake new trials with a wider range of HNS subjects as part of a broader programme of research using a range of more efficient lamp types.

Transport, storage and handling of cuttings

Both unrooted and rooted cuttings are now purchased from a range of suppliers and often from over long distances (sometimes outside the UK and even Europe) but little or no work has been done to establish optimum storage, handling and transport periods for different types of material, from which best practice guidelines could be developed for growers. Given the increasing volumes of cuttings that are now outsourced by UK growers, there is a pressing need for benchmarking work around which practical guidelines could be established.

Health status of cuttings

There is a need to enable growers to undertake their own disease screening tests, for example, using reliable and rapid diagnostic tests to enable on-site checks for a range of fungal, bacterial and viral diseases.

Accurate on-site tests for diseases would speed up diagnosis and treatment

Propagation environments and systems

Water management

Striking the right balance between adjusting mist levels to reduce water loss from leafy cuttings while avoiding waterlogging of the rooting medium can be difficult to achieve. Potentially, capillary sand beds offer a solution, although covering the beds with membranes to control weeds, prevent rooting through and to keep pots clean may, however, impede good capillary contact and so drainage. Capillary matting is also sometimes used and further work is needed to evaluate ways of improving drainage from beds.

Related to this is the nature of the rooting medium, type of plug and tray, and how they may affect drainage of the media and potential rooting. There is a need, therefore, for research to compare rooting results of different systems and find practical ways for growers to measure the air and water content of media across a range of plug and media types.

The role of the Evaposensor

Related to water management under mist, systematic comparisons of different mist regimes to identify optimal set points for particular species and cultivars are needed to enable nurseries to get the best from the Evaposensor mist control equipment.

Aftercare

Crop protection

There is interest in the use of various microbial products to aid preventative disease control, either incorporated into the growing medium or applied as drench treatments. Interest so far has largely centred on their use to control root and stem base fungal infections in specific crops. Such products link well with current moves towards greater use of integrated crop management and may have a wider role to play in propagation situations, where they are relatively safe. There is a need to review and screen a range of these products to assess their effects.

Integrated pest management

The higher temperature and humidity environments of propagation restrict the range of biological control agents and release methods that can be used in such situations. It is often, therefore, necessary to adopt different tactics when using IPM in propagation situations and not all growers appreciate how best to devise and adjust programmes accordingly. The frequent arrival of new products, both biological control agents and biopesticides, can also make it time-consuming to keep up to date with information. Further knowledge transfer would be timely to provide this information.

Granulated cork as a mulch (left) used to suppress liverwort at propagation

Integrated crop management

AHDB Horticulture project HNS 185: ***Understanding and managing crop protection through integrated crop management**,* found that many growers are aware of integrated crop management and the implemention of such measures. This suggests there should be little difficulty in meeting at least some of the requirements of the EC Sustainable Use Directive (SUD), which, as part of the Directive, necessitates growers to reduce the use of pesticides and demonstrate good practice by 2014.

However, there is a need for further knowledge transfer on the more technical aspects of integrated crop management, such as the propagation of disease-free material, including the use of on-site diagnostic tests and their utilisation for the detection of latent infections in plant material.

Liverwort and moss control

Both of these weeds continue to pose problems to propagators and there is a need to reinforce the benefits of cultural control measures and good nursery hygiene linked to the use of alternative, non-chemical weed control options. AHDB Horticulture factsheet 25/12 ***Non-chemical weed control for container-grown hardy nursery stock***, provides detailed guidance on non-chemical weed control. Further knowledge transfer that raises awareness of alternatives to chemicals, underlines the value of nursery hygiene and cultural weed control measures, and demonstrates application equipment would help reinforce best practice.

There is also a limited number of pesticides that provide good moss and liverwort control and these should be screened with a view, if effective, to appropriate approvals being sought.

Cold storage of rooted plugs and liners

The ability to hold rooted cuttings in modules and pot liners for short periods until required was one of several benefits identified by AHDB Horticulture project HNS 113: ***The feasibility of using low temperature storage as a scheduling aid in nursery stock production**,* reducing the need for subsequent growth control and enabling the development of scheduled production programmes.

No published work appears to have been done to determine more precisely the temperature requirements of HNS species when stored in this way. While 3–4°C is likely to be a good starting point and is used for bedding plants, research is needed to develop a more specific understanding of HNS requirements, which would enable firmer guidelines to be developed for growers to exploit cold storage for scheduling purposes in numerous ways.

Table 27 summarises the current research and knowledge transfer requirements.

Cold stores could be better utilised to schedule HNS production

Table 27. Current research and knowledge transfer requirements

Section	Subject	Work required
Propagation management	Stock plant and cutting nutrition	Research on the nutrient requirements of stock plants and cuttings, particularly with the more difficult to root subjects
	Cold storage of leafy cuttings	Research to determine optimum storage times and temperatures to develop specific guidelines for HNS subjects
	Lean management and its application to propagation work	Knowledge transfer tailored to the needs of propagators to build confidence and raise awareness of the benefits of this technique
	Wounding of cuttings	Research to identify optimum wounding techniques for difficult-to-root subjects (linked with new work on rooting hormones)
	Leaf removal from cuttings	New research with a wider range of subjects to substantiate and build on previous work as a basis for crop recommendations
	Rooting hormones	Research to identify optimum formulations, combinations and rates for a range of HNS subjects
Propagation techniques	Improving propagation of difficult to root subjects from cuttings	Research to define optimum stock plant management, propagation timing, types of cuttings, treatments and rooting environments
	Physiology of rooting	New research to better understand why some cuttings root easier than others to help improve strike rates with more difficult subjects and enable the rooting of easier subjects to be better scheduled in line with market requirements
	Preconditioning cutting material	Linked to stock plant management, new work on dark preconditioning and lighting with a wider, more contemporary range of subjects to develop practical, best practice guidelines for improved rooting using these techniques
	Transport, storage and handling of cuttings	Research and development work to determine optimum transport and handling periods for rooted and unrooted cuttings, around which best practice guidelines can be established
	Health status of cuttings	Continued development of on-site diagnostic kits for rapid and reliable disease screening of cutting material, such as *Heuchera* rust, bacterial and viral infections
Propagation environments and systems	Water management under mist systems	Research to compare rooting results on capillary beds under mist, using a range of systems, rooting media and plug trays. Find practical ways for growers to measure the air to water content of media across a range of plug and media types
	The role of the Evaposensor	Systematic comparisons of different mist regimes to identify the optimal set points for particular species and cultivars to enable nurseries to get the best from the Evaposensor mist control equipment
Aftercare	Crop protection	Research to evaluate benefits and role of microbial products in HNS propagation
	Integrated crop management	Knowledge transfer to build confidence and promote best practice, propagation and maintenance of disease-free material
	Liverwort and moss control	Research on potential products for control would be useful along with cultural control and non-chemical control strategies
	Cold storage of rooted plugs and liners	Research on HNS requirements providing firmer recommendations for growers

Appendix I – Dealing with common problems

Management and materials			
What?	Where?	Why?	What to do
Insufficient or poor quality propagation material	General problem but usually most common during the busy spring and summer periods	Inadequate stock plant management, including poor clones, insufficient plants, lack of proper and timely pruning, poor husbandry Old stock plants no longer sufficiently productive Shortage of suitable nursery crops from which to propagate Supplier issues if buying in cutting material	No ‘quick fix’ other than buying in material or liners or delay propagation until suitable material becomes available from stock Look ahead, forward plan future stock plant requirements to ensure sufficient high-quality material is available when required Use clonal true to type stock of high health status when establishing stock beds Ensure good husbandry to maintain productivity Prune stock plants regularly and appropriately to maximise high-quality cutting material and rooting Replace plants on a regular and phased cycle to ensure continuity of supply Only buy in cutting material from reputable suppliers and don’t just rely on one supplier Where soft cuttings are in short supply, root an early batch and take ‘cuttings from cuttings’; it usually works well for quick rooting soft material
Slow throughputs during cutting collection, preparation and insertion	Commonplace during busy periods and with difficult-to-prepare cutting material, for example, large-leaved or thorny stemed subjects	Inadequate or inefficient use of resources Poor staff supervision Poor preparation technique Unnecessary leaf removal from cuttings	Review staff resources, procedures, work place layouts and training needs Use a reliable staff member to ‘service’ the work, ensuring team members don’t run short of materials and so are able to work continuously Review cutting handling procedures No need to strip leaves from many subjects, such as *Berberis* (evergreen), *Hebe, Heathers, Pyracantha* and *Viburnum tinus* Monitor outputs throughout the day
Insufficient plug plants or liners for sale or growing on	Can happen with anything but particularly with slow or difficult-to-root subjects where wastage may be high due to propagation losses or where suitable propagation material is limited, especially where timing is crucial for optimum rooting	Bad planning and over optimistic forecasts for particular crops Not building in sufficient contingencies for slower, more difficult, higher risk crops Inadequate or unsuitable propagation material Poor propagation and liner performance leading to losses	Be realistic when planning, allow sufficient time for crops to root well, grow on and form well-branched liners Build in contingency measures (such as extra cuttings), especially for more difficult subjects Practice good stock plant management to ensure ready and timely supplies of adequate propagation material Review and amend schedules based on previous experience and records

Seed propagation			
What?	**Where?**	**Why?**	**What to do**
Poor seed germination	General problem	Seed dormancy Poor seed quality and storage Seed sown at wrong time for species Seed sown too deeply Incorrect germination temperature; usually, the problem is often low temperatures but, sometimes, too high a temperature will inhibit germination Germination may be naturally slow (for example as with delayed hypogeal germination of *Paeonia*) Soil or growing media has dried out Waterlogging Mice damage	Check seed dormancy, quality and sowing time is appropriate for species Sow *Aesculus, Castanea, Fraxinus* and *Quercus* in the autumn rather than spring as well as herbaceous subjects such as *Alchemilla, Euphorbia, Gentiana, Libertia* and *Primula* Process and store seed quickly once collected, while fresh and in good condition. Use hessian sacks when collecting seed rather than polythene bags, keep seed cool and transfer to cold storage (3°C) promptly Use cold storage to break dormancy and maintain seed viability between collection and sowing Check and amend sowing depths (usually, twice the depth of the seed will suffice) Ensure base heat is adequate and delivering requisite temperatures for germination with indoor sowings Ensure seed beds and propagation media are well drained and not over watered Check to ensure mice or similar pests are not damaging seeds
Seedlings collapsing and failing to establish	General problem	Conditions too wet or too dry Pest damage Damping-off disease or similar *Botrytis* infection	Check moisture status and drainage of propagation medium and amend as necessary Check for signs of pests or diseases on roots and stem bases, removing affected plants or trays and using suitable control measures
Poor seedling growth and colour (paling or purpling)	General problem	A cool growing environment with indoor sowings Poor nutrient uptake Pest or disease problem	Check and amend growing temperatures as necessary; chilling will reduce root activity and, in turn, nutrient uptake, notably of phosphate and iron, deficiencies of which can lead to leaf chlorosis, paling and purpling A low temperature can also cause leaf purpling Check for signs of damping-off or black root rot disease

Cutting propagation and rooting environments			
What?	**Where?**	**Why?**	**What to do**
Poor or slow rooting of cuttings	General but usually most pronounced with slow or difficult-to-root subjects	Some subjects are naturally slow rooting Poor quality material Material in floral condition rather than vegetative Poor or inappropriate preparation Inappropriate rooting environment Incorrect timing or type of cutting Too much or not enough rooting hormone Inappropriate rooting medium	Only use healthy, uniform and good quality cuttings, taken from stock plants or strong growing nursery crops Prepare cuttings carefully, using strong shoots, wounding and using hormone 'quick dips' where beneficial (for semi-ripe, slow or difficult-to-root subjects and hardwood cuttings) For more difficult subjects, take cuttings at the optimum time for rooting; in the case of Acer, *Azalea*, *Cotinus* and *Syringa* during April and May as softwood cuttings under high humidity mist or fog Use a light slice wound with firmer, harder wood and 'quick dip' hormones rather than talc preparations with *Daphne* and *Rhododendron* species and difficult-to-root evergreens and conifers Use supportive, high humidity rooting environments for slow or difficult to root species Check the rooting medium mix; use peat, grit and bark with conifers and *Taxus* for best results Consider other forms of propagation, such as seed, root cuttings, etc
Uneven rooting	General	Weak or poorly graded propagation material	Ensure material is well graded during collection and preparation
Excess callus formation around cutting bases	General, can be common in slow-rooting evergreens and conifers	A high rooting temperature Excessive aeration linked to watering and, in turn, alkalinity build-up of the rooting medium (for example, with *Camellia, X Cupressocyparis leylandii* and *Taxus*) Excessive wounding or hormone application	Check and reduce rooting temperatures if required, ensure the propagation medium is well structured but not excessively open and avoid overzealous hormone application (use a five-second 'quick dip' for best results, generally) Easy rooting summer propagated material seldom requires much base heat, wounding or use of hormone rooting aids
Waterlogged and rotting cuttings	General but usually more common among autumn and winter propagated crops although this can occur in poorly controlled mist environments	Poor water management Waterlogged rooting medium	Check and correct watering regimes and humidity controls in mist and fog systems. Use a sensor for most accurate control Ensure both the propagation medium and propagation bed are well drained Use bark or wood-fibre in the rooting medium Avoid high relative humidity around overwintered cuttings under protection Use capillary sand beds (or porous concrete floors) to form propagation beds and provide positive drainage

Cutting propagation and rooting environments (continued)			
What?	**Where?**	**Why?**	**What to do**
Wilting and collapse of cuttings	General but most common with early season softwood leafy cuttings, including *Acer*, *Azalea*, *Cotinus* and *Syringa* Common in spring and summer if material is collected at the wrong time and not handled or stored promptly	Water loss due to leaf warming and rapid evapotranspiration Poor handling and storage of cutting material in the field prior to preparation and insertion Collecting material during hot periods	Harvest cuttings when conditions are cool and fresh, and transfer to cool, shaded conditions promptly Use cold storage (3°C) for short-term holding of cutting material and to remove 'field heat' Use supportive rooting environments for softwood leafy cuttings Check and amend shade levels, especially with spring and summer propagated crops under polythene Ensure both plant material and media in trays and pots don't dry out
Root constriction, curling and damage	General problem but worse when cuttings are rooted in standard trays and loose-filled plug trays and are left too long before handling HNS subjects that dislike root disturbance (including *Arbutus*, *Garrya* and herbaceous plant subjects such as *Alstroemeria* and *Dierama*) suffer most Likewise, rooting down into beds by vigorous subjects (such as *Acanthus*, *Buddleia*, *Elaeagnus*, *Euphorbia cyparissias* and *Hydrangea*) can be a problem, especially on capillary sand beds	Delays in handling and potting on rooted material Worse with standard trays or where cells and pots are too small for the size of cutting or vigour of plant Vigorous subjects can be a particular problem, in terms of root constriction, curling and rooting through into beds Capillary sand beds that are kept too wet for too long near the surface exacerbate rooting through	Use modules and choose the right size for the subject For softwood cuttings, use modules with pre-drilled holes to ease insertion, or loose-fill plug trays Root-trainers and biodegradable trays and pots help reduce root constriction Use permeable membranes over sand beds to reduce rooting through Don't let sand beds sit too wet, especially near the surface as this draws roots down Pot on rooted material promptly

Cutting propagation and rooting environments (continued)			
What?	**Where?**	**Why?**	**What to do**
Cuttings or liners drying out and scorching	Softwood and semi-ripe leafy cuttings	High light levels, inadequate shading and rapid water loss Water scorch from overhead irrigation applied during hot, bright conditions Spray scorch from pesticide application	Increase shading and ventilate crops as conditions permit Avoid overhead watering during very hot, bright periods unless crops are well shaded Only spray pesticides when necessary and never during hot, bright spells when leaf scorch can easily occur; spray in the early morning or evening, use biological pest control options where possible
Cuttings producing shoots but few or no roots formed	General but quite common with hardwood cuttings unless rooting environment is well managed and can be a problem with fast-growing herbaceous subjects	Most usually, due to too high an air temperature causing buds to break and shoots to grow ahead of root formation	Reduce air temperatures (ventilate, shade, use fans) to control growth Move protected crops outside if sufficiently established Use cold storage to hold rooted and unrooted material for short periods to control growth
Micropropagation			
What?	**Where?**	**Why?**	**What to do**
Micropropagated plantlets failing to establish	Most common with stage 3 plantlets, which require careful weaning	Drying out or over wetting are common causes but also physical damage during transit or subsequent handling A large amount of material arriving at the same time may create handling and weaning difficulties Difficult subjects weaned in less visible locations can lead to problems Delays in pricking out stage 3 material on arrival and transferring swiftly to a suitably supportive environment Weaning large batches of plantlets in the heat of midsummer rather than spring is more stressful to young plants and can lead to losses	Schedule deliveries so they don't all arrive at once Handle young plant material quickly on arrival, prick out swiftly and use a high humidity environment to wean and establish them (wet fog, closed mist or polythene tent plus fleece covers) Wean plants in a highly visible place so they can be seen and checked at least daily Avoid weaning in the heat of midsummer if possible; the extra heat stress can make weaning especially difficult Use plenty of summer shade Buy in difficult-to-establish subjects (such as *Heuchera*) as weaned plantlets (stage 4) not rooting cultures (stage 3)

Grafting and budding			
What?	Where?	Why?	What to do
Poor graft take	Not specific to any particular subject	Poor quality stocks (a thin stem diameter) or scion wood Poor rootstock handling and storage (including frost damage or desiccation) Stock and scion may not be compatible Graft union floods (bench grafting) Graft union dries out Timing (some subjects respond better during specific periods) Poor knife-work and failure to make good cambial contact Poor or lack of training in grafting	Use strong stocks (usually two years old for adequate stem thickness for grafting, especially for field grafting) Use only strong, well-ripened, one-year wood for scions Check stock and scion are compatible Bring stocks inside at least six weeks ahead of bench grafting to dry back and promote strong root growth Wax conifer grafts to prevent drying out Check timing: hardwoods (winter), conifers (mainly February and March but graft cedars in summer), *Acers* and *Hamamelis* (summer) Use gentle base heat for winter bench grafting of hardwoods or hot-pipe callusing Don't tie-in too tightly Keep a 'sap-drawer' (active shoot) where required and reduce gradually once the union has formed
Bark/rind difficult to lift	Roses ('T' budding)	Dry field conditions prior to budding Temperatures too low for adequate sap flow	Aim to bud following steady rain or irrigation Delay budding
Poor bud take	Not specific to any particular subject	Poor quality stocks or bud wood Bud wood has dried out Timing (too early or late depending on season and subject) Bud ties too tight Poor knife-work and cambial contact (chip budding) Poor or lack of training in budding skills	Don't use soft tips or well ripened stem bases when preparing buds Keep bud wood cool, moist and away from direct sun (use a cold store if more than 24 hours) Chip bud *Malus* early and *Prunus* later, T-bud roses from early July Use a sharp knife, work quickly, neatly and accurately

Aftercare			
What?	**Where?**	**Why?**	**What to do**
Recurring problems with pests and diseases	General but most common in spring and summer propagation crops, although damping-off, sciarid fly and vine weevil larvae can damage autumn and winter crops, especially young seedlings and newly rooted cuttings	Inadequate crop protection measures, poor hygiene and contaminated propagation material, plugs and liners	Ensure good nursery hygiene Check bought-in plugs, stock plants and liners carefully on arrival for signs of problems and treat before transfer to nursery Monitor propagation and liner crops regularly; check seed and cuttings daily Use sticky traps to monitor flying pests like whiteflies, thrips and sciarid fly adults Use biological control agents where available for safe and effective control of pests
Weeds (including moss and liverwort) frequently occurring in propagation areas and liners	General problem where nursery hygiene and water management is poor. Often worst among slow-rooting subjects, especially in the autumn and winter period	Poor nursery hygiene Weed infested plugs Contaminated water, media or tools, etc. Overly wet propagation environments or poor water management	Review nursery hygiene measures and correct where necessary to reduce background weed pressure Cover water tanks and growing media storage areas Clean, disinfect or change tools regularly Keep water management under close control to avoid overly wet conditions that favour weeds Use mulches or permeable tray mats to control weeds in plug trays and pot liners Use permeable membranes over sand beds to help keep them clean
Rooted cuttings appear pale and failing to grow away well	Common problem where material is held for lengthy periods before liner potting, particularly among quick-rooting and vigorous subjects propagated during the spring and summer	Cuttings may have low carbohydrate reserves due to poor nutrient status of stock plants or nursery crops from which they were taken or nutrient leaching may have occurred during propagation Nutrient levels in rooting medium are low or have expired	Liquid feed (50 ppm nitrogen + 25 ppm phosphorus + 50 ppm potassium) rooted cuttings to boost nutrient reserves and restore colour; use foliar feeds if the medium is sufficiently wet and this precludes liquid feeding Use controlled release fertilisers in the propagation medium to sustain growth and quality of rooted material

Aftercare (continued)			
What?	**Where?**	**Why?**	**What to do**
Excessive growth of rooted material or liners	Common with fast-growing summer propagated crops grown on under protection	Vigorous varieties can be difficult to contain but high temperatures and high nitrogen feed programmes encourage soft, rapid growth, especially under protection Poor planning and crop scheduling often create a need for growth control and can result in high crop waste if supply is not well matched to demand	Reduce growing temperatures and transfer established crops outside in summer Schedule production better to save trimming or pruning Ease back feeding and irrigation regimes Consider using low-rate chemical growth regulators on established liners alongside cultural measures
Poor winter survival of rooted cuttings	General problem where rooted cuttings or liners have not developed sufficiently strong roots prior to winter	Direct tissue damage by sub-zero winter temperatures Waterlogging of trays, pots or beds Poor environmental control (high relative humidity around cuttings) Poor nursery hygiene leading to pest and disease carry-over Poor rooting of cuttings, late propagation or potting of liners Use of inferior, poor quality cutting material	Provide adequate winter protection (including heat, fleece covers etc.) and ensure cuttings and same season potted liners are well established prior to winter Ensure beds, pots and trays are well drained Practice good environmental control to prevent material overwintering in high humidities, which encourages diseases and decay Use only strong, good quality propagation material and propagate or pot early to enable cuttings or liners to form good roots ahead of winter

Appendix II – A summary of propagation methods for a range of woody HNS subjects

HNS subjects	Seed	Softwood cuttings	Semi-ripe cuttings	Hardwood cuttings	Leaf-bud cuttings	Root cuttings	Division	Field grafting	Bench grafting	Budding	Layering/ stooling	Micropro-pagation
Abelia		●	●									
Abutilon	●	●	●	●								
Acer palmatum		●							●			
Acer negundo		●	●						W & S	●		
Actinidia			●									
Arbutus	●		B									
Aucuba			●	●							●	
Azalea (deciduous)		●									●	●
Azalea (evergreen)			●									●
Berberis (deciduous)	●		●				●					
Berberis (evergreen)	●		●						W			
Betula species	●	●	●						W	●		●
Buddleia		●	●	●								●
Buxus			●	●			●					
Camellia			●									
Carpinus	●		●						W			
Caryopteris		●	●									
Ceanothus			●									
Cedrus	●								S			
Ceratostigma		●	●									
Cercidiphyllum	●	B									L	
Cercis	●	●							W			
Chaenomeles		●	●	●		●					L	
Chamaecyparis			●						●			
Chimonanthus	●	●									L	
Choisya		●	●									
Cistus		●	●									
Clematis	Species	●	●						W			●
Clerodendron trichotomum		●				●						
Convolvulus cneorum		●	●									
Cornus alba cultivars		●	●	●							L	●
Cornus florida		●	●						W & S		L	●
Cornus kousa									W & S		●	

HNS subjects	Seed	Softwood cuttings	Semi-ripe cuttings	Hardwood cuttings	Leaf-bud cuttings	Root cuttings	Division	Field grafting	Bench grafting	Budding	Layering/ stooling	Micropro- pagation
Corylopsis	✓	✓	✓								L	
Cotinus		✓									L	
Cotoneaster	✓	✓	✓							✓		
Crataegus	✓							✓		✓		
Crinodendron		B	B									
Cryptomeria	✓		✓						W			
X Cupressocyparis leylandii			✓									
Cupressus	✓		✓						S			
Cytisus	✓		✓	✓								
Daphne	*D. mezerum*		✓								L	
Davidia	✓	B							W & S		✓	
Desfontainia			B									
Deutzia		✓	✓									
Drimys		B	B									
Elaeagnus			✓									
Embothrium			✓			✓						
Enkianthus	✓	✓										
Erica			✓	✓								
Escallonia			✓	✓								
Eucalyptus	✓	✓				✓						✓
Eucryphia	Species		✓									
Euonymus	✓		✓						W			
Exochorda		B										
Fagus≠	✓								W			
Fothergilla		B	B								L	
Fraxinus	✓							✓	W	✓		
Fuchsia		✓	✓	✓								
Garrya			B	B								✓
Genista	✓		✓									
Ginkgo	✓								W			
Griselinia			✓	✓								
Hamamelis	Species	B							S		✓	✓
Hebe		✓	✓									✓
Hedera			✓									

HNS subjects	Seed	Softwood cuttings	Semi-ripe cuttings	Hardwood cuttings	Leaf-bud cuttings	Root cuttings	Division	Field grafting	Bench grafting	Budding	Layering/ stooling	Micropro-pagation
Hippophae rhamnoides	●											
Hoheria			●									
Hydrangea		●	●									●
Hypericum		●	●	●								
Ilex	●		●							●		
Jasminum			B	●								
Juglans	●								W			
Juniperus		●	●									
Kalmia	●											●
Kerria		●	●	●			●					
Koelreuteria paniculata	●					●						
Kolkwitzia amabilis		●	●	●								
Laburnum	●								W	●		
Laurus nobilis			●	●								
Lavandula	Species	●	●	●								
Lavatera		●	B									
Leucothoe	●		B									
Leycesteria formosa	●		●	●								
Ligustrum		●	●	●								
Liquidambar styraciflua	●	●							W		L	
Liriodendron tulipifera	●								W			
Lithospermum			●									
Lonicera (shrubby)		●	●	●								
Lonicera (climbers)		●	●	●								
Magnolia		●	●						●	●	L	●
Mahonia	●		B		●							
Malus								●	W	●	●	
Metasequoia glyptostroboides				●					W			
Myrtus			B									
Nandina domestica			●									
Nothofagus	●		●								L	
Olearia			●	●								
Osmanthus			●									
Pachysandra			●				●					

HNS subjects	Seed	Softwood cuttings	Semi-ripe cuttings	Hardwood cuttings	Leaf-bud cuttings	Root cuttings	Division	Field grafting	Bench grafting	Budding	Layering/ stooling	Micropro-pagation
Paeonia	■								S			
Parrotia persica									W & S		■	
Parthenocissus		■	■	■							L	
Passiflora caerulea		■	■									
Paulownia tomentosa	■											
Pernettya mucronata			B				■					
Philadelphus		■	■	■								
Phlomis			■									
Photinia			■									■
Picea	■		■						S			
Pieris	■		B								L	■
Pinus	■								■			
Pittosporum	■		B									
Platanus x acerifolia (hispanica)				B							St	
Potentilla		■	■	■								
Prunus (deciduous)		■	■	■		■		■	W	■	St	
Prunus (evergreen)			■									
Pyracantha			■									
Quercus	■								■			
Rhododendron (dwarf)	■		■									■
Rhododendron (large)			■						W			■
Rhus typhina						■						
Ribes			■	■								
Robinia	■								■			
Romneya coulteri						■						
Rosa	■	B	■	■					■	■		■
Rosmarinus			■									
Ruscus aculeatus							■					
Ruta graveolens		■	■									
Salix		■	■	■					W			
Salvia officinalis		■	B									
Sambucus		■	■	■								
Santolina		■	■	■								
Sarcococca		B	B				■					

HNS subjects	Seed	Softwood cuttings	Semi-ripe cuttings	Hardwood cuttings	Leaf-bud cuttings	Root cuttings	Division	Field grafting	Bench grafting	Budding	Layering/ stooling	Micropro-pagation
Senecio		■	■									
Skimmia	■		■	■								
Solanum			■									
Sorbus	■								■	■		
Spiraea		■	■									
Symphoricarpos		■	■	■								
Syringa		B							■		L	■
Tamarix			■	■								
Taxodium distichum	■			■								
Taxus	■		■	■					■			
Thuja	■		■									
Tilia	■		■						W	■	L	
Ulex europaeus		B	B	■								
Ulmus			■			■			W	■	L	
Viburnum (deciduous)		■		■							L	
Viburnum (evergreen types)			■						S			
Viburnum (spring flowering)		B	B									
Vinca		■	■				■					
Weigela		■	B	■								
Wisteria			B	■					W		L	

Key

B Use basal cuttings where available **L** Layering **S** Summer bench grafting **St** Stooling **W** Winter bench grafting ■ Preferred propagation method

Note

As a general guide, seed propagation, where highlighted, is for the species of a genus and vegetative propagation is preferred for the cultivars (which do not usually come true from seed). However, many species are also readily propagated from cuttings. Grafting and budding techniques are normally used for propagating cultivars.

Appendix III – References and further information

Propagation management

AHDB Horticulture factsheets

- 09/05: *Low temperature storage of bedding plant plugs*
- 05/05: *Nutrition of container-grown hardy nursery stock*
- 14/04: *Hardy nursery stock – Management of stock plants*
- 23/97: *Pruning and preconditioning stockplants of ornamental shrubs*

AHDB Horticulture grower guides

- HNS *Cold Storage – How to successfully cold store hardy nursery stock*

AHDB Horticulture project reports

- HNS 140: *Survey to determine current industry practice and future needs for the use of low temperature storage*
- HNS 136a: *Management tools for optimising nursery space use and production forecasting*
- HNS 113: *The feasibility of using low temperature storage as a scheduling aid in nursery stock production*
- HNS 41: *Stock plant management and preconditioning*
- HNS 27: *Propagation: Stock plant and cutting processes influencing subsequent plant quality*
- HNS 14: *Clonal selection of hardy ornamental nursery stock cultivars*
- PC 196a: *Bedding plants: The use of low temperature storage as a scheduling aid in bedding plant production*

Other sources of information

- Delft van, P., 2005. Preparing for a new propagation unit. IPPS Combined Proceedings 55: 243-247
- HRI Efford EHS HONS Programme Reports 1981 and 1982
- HRI Efford EHS HONS Reviews 1977, 1978, 1982, 1983, 1984
- Lamb, J.G.D., Kelly, J.C., and Bowbrick, P., 1985. Nursery Stock Manual, Grower Books
- Macdonald, B., 2000. Practical Woody Plant Propagation for Nursery Growers, Timber Press
- O'Neill, K., 2005. Advantages of in-house propagation at Bransford Webbs Plant Company IPPS Combined Proceedings 55: 247-249
- Schonbeck, H., 1982. Is stripping cuttings necessary? IPPS Combined Proceedings 32: 199-200
- Stanley, J. and Toogood, A., 1980. The Modern Nurseryman, Faber and Faber

Propagation techniques

AHDB Horticulture factsheets

- 29/97: *Containerising field budded trees*
- 26/97: *Field budding ornamental trees*

AHDB Horticulture grower guides

- Herbaceous perennials – *A guide to the production of container-grown plants*
- HNS Cold Storage – *How to successfully cold store hardy nursery stock*
- Practical weed control for nursery stock – *An AHDB Horticulture growers' handbook*

AHDB Horticulture project reports

- CP 74: *Exploiting ethylene and wounding signalling to promote adventitious root formation in hard-to-root ornamental species*
- HNS 155: *Nursery stock: Herbicide screening for tree seed beds*
- HNS 45: *Management opportunities in the budding nursery*
- HNS 40a: *Optimising pruning of micropropagated and conventional propagated container-grown plants*
- HNS 32: *Factors controlling the quality of micropropagated HNS liners*
- HNS 31a: *Tree and shrub seed beds: Continued evaluation of weed control treatments*
- HNS 31: *Evaluation of weed control treatments in tree and shrub seed beds and first outdoor transplants*
- HNS 29: Acer: *Control of Verticillium wilt*
- HNS 20a: *EMLA ornamental* Prunus *and* Malus *varieties and rootstocks: Field trials to promote their uptake*
- HNS 7 and 7a: *An analysis of why bud grafting gives poor and inconsistent results for many ornamental trees*

Other sources of information

- Coombes, A. and Hillier J., (Ed), 2002. Hilliers Manual of Trees and Shrubs (8th Edition), David and Charles
- Dunn, N.A., 1995. The use of hot-pipe callusing for bench grafting. IPPS Combined Proceedings 45: 139-141
- Edmonds, J.,1980. Container Plant Manual, Grower Books
- Garner, R.J., 2003. The Grafters' Handbook, Casell
- Lamb, J.G.D., Kelly, J.C., and Bowbrick, P., 1985 Nursery Stock Manual, Grower Books
- Macdonald, B., 2000. Practical Woody Plant Propagation for Nursery Growers, Timber Press
- McMillan-Browse, P.D.A., 1979. Hardy woody plants from seed, Grower Books
- Sheat, G.W., 1948. Propagation of trees, shrubs and conifers, Macmillan

- Stanley, J. and Toogood, A., 1980. The Modern Nurseryman, Faber and Faber
- Wells, J. S., 1985. Plant Propagation Practices. American Nurseryman

Propagation environments and systems

AHDB Horticulture project reports

- HNS 159: *Nursery stock propagation: Nursery evaluation and demonstration of the Evaposensor towards its commercial availability as a mist controller*
- HNS 76: HNS: *Examination of techniques to raise humidity in mist houses*
- HNS 9: *Understanding the environmental needs of leafy cuttings during rooting*

Other sources of information

- ADAS Pamphlet P3002, 1986. Sun tunnel propagation of softwood cuttings
- HRI Efford EHS HONS Programme Reports 1981 and 1982
- HRI Efford EHS HONS Reviews 1977, 1978, 1982, 1983, 1984
- Humphrey, B.E., 1985. Commercial aspects of direct sticking of cuttings at Hilliers. IPPS Combined Proceedings 35: 464-468
- Kelly, A., 1986. Direct sticking of evergreen Azalea cuttings. IPPS Combined Proceedings 36: 333-335
- Lamb, J.G.D., Kelly, J.C., and Bowbrick, P., 1985 Nursery Stock Manual, Grower Books
- Macdonald, B., 2000. Practical Woody Plant Propagation for Nursery Growers, Timber Press
- Scott, M.A., 1985. Progress with direct sticking of cuttings. IPPS Combined Proceedings 35: 458-463
- Stanley, J. and Toogood, A., 1980 The Modern Nurseryman, Faber and Faber

Aftercare

AHDB Horticulture factsheets

- 30/97: *Maximising cutting survival during winter*
- 05/01: *Glasshouse whitefly and leafhoppers in protected herbs: Options for control within IPM programmes*
- 01/02: *Growth regulation of ornamental plants by reduced phosphorus availability*
- 14/04: *Hardy nursery stock – Management of stock plants*
- 16/04: *Control of* Phytophthora, Pythium *and* Rhizoctonia *in container-grown hardy ornamentals*
- 05/05: *Nutrition of container-grown hardy nursery stock*
- 08/05: *The biology and control of two-spotted spider mite in nursery stock*
- 09/05: *Low temperature storage of bedding plant plugs*
- 13/06: *Caterpillars of protected ornamental crops*
- 10/07: *Guidelines on nursery hygiene for outdoor and protected ornamental crops*
- 06/08: *A guide to best practice in handling bought-in plants*
- 13/09: *Guidelines for minimising latent grey mould in cut flowers and pot plants*
- 25/12: *Non-chemical weed control for container-grown hardy nursery stock*
- 03/14: *Use of chemical disinfectants in protected ornamental production*
- 20/15: *Control of whiteflies on protected ornamental crops*
- 24/16: *Vine weevil control in hardy nursery stock*
- 18/17: *Methods and equipment for matching irrigation supply to demand in container-grown crops*

AHDB Horticulture grower guides

- *Hardy nursery stock Crop Walkers' Guide*
- *Bedding and pot plants Crop Walkers' Guide*
- HNS Cold Storage – *How to successfully cold store hardy nursery stock*
- *Practical weed control for nursery stock* – An AHDB Horticulture growers' handbook.

AHDB Horticulture project reports

- HNS 185: *Understanding and managing crop protection through integrated crop management*
- HNS 175: *Liverwort control in HONS using novel techniques*
- HNS 155: *Nursery stock: Herbicide screening for tree seed beds*
- HNS 126: *Biology, epidemiology and control of liverwort infestation of nursery plant containers*
- HNS 125: *Hardy Ornamentals: The potential of compost teas for improving crop health and growth*
- HNS 113: *The feasibility of using low temperature storage as a scheduling aid in nursery stock production*
- HNS 105 and 105b: *Hardy nursery stock: Integrated control of snails and slugs*
- HNS 97: *Improving the control and efficiency of water use in container-grown hardy ornamental nursery stock*
- HNS 93c: *Protected container-grown nursery stock: Chemical and non-chemical screening for moss and liverwort control in liners*
- HNS 93: *Nursery stock propagation: Moss, liverwort and slime control*
- HNS 90: *Nursery stock propagation: Nutrition of rooted cuttings in modular trays*
- HNS 84: *Development of effective overwintering strategies for rooted cuttings and young liners*

- HNS 69: *Ornamental shrubs: Developing the concept of the designer liner*
- HNS 55: *Strategies for liner production designed to achieve high-quality container plants*
- HNS 49b: *Influence of environmental factors and crop management on the incidence of disease on liners of overwintered hardy nursery stock species*
- HNS 44: *Pre and post-rooting storage of softwood and hardwood cuttings*
- HNS 42 and 42a: *Supplementary lighting for alpines, herbaceous perennials and hardy nursery stock species*
- HNS 39 and 39a: *Container-grown nursery stock: Growth regulation*
- HNS 35g: *Chemical weed control in container-grown nursery stock under protection*
- HNS 35b: *Container HNS: Herbicide screening under protection*
- HNS 31a: *Tree and shrub seed beds: Continued evaluation of weed control treatments*
- HNS 31: *Evaluation of weed control treatments in tree and shrub seed beds and first outdoor transplants*
- HNS 27: *Propagation: Stock plant and cutting processes influencing subsequent plant quality*
- PC 239 and PC 239a: *Protected herbs, ornamentals and celery: Development of an on-nursery rearing system for Atheta coriara for reduced cost biological control of sciarid and shore flies*

Other sources of information

- Barba, R.C. and Pokorny, F.A., 1975. Influence of the photoperiod on the propagation of two Rhododendron cultivars. J. Hort Sci., 50: 55-9
- HRI Efford EHS HONS Programme Reports 1981 and 1982
- HRI Efford HONS Reviews 1977, 1978, 1982, 1983, 1984
- Kelley, J.D., 1965. Rooting of cuttings as influenced by the photoperiod of the stock plant. Proc. Int. Pl. Propag. Soc., 15: 186-9
- Kramer, P.J., 1937. Photoperiodic stimulation of growth by artificial light as a cause of winter killing. Plant Physiol. 12: 881-883
- Lamphear, F.O. and Meahl, R.P., 1963. Influence of endogenous rooting co-factors and environment on seasonal fluctuation in root initiation of selected evergreen cuttings. Proc. Am. Soc. Hort. Sci., 83: 811-18
- Loach, K. and Whalley, D.N., 1975. Use of light, carbon dioxide enrichment and growth regulators in the overwintering of hardy ornamental nursery stock cuttings. Acta Horticulturae, 54: 105-116
- Loughall Research Station Annual Report, 1979
- Vince-Prue, D., 1975. Photoperiodism in plants. McGraw Hill, London
- Waxman, S., 1955. The effect of the length of day on the growth of woody plants. Proc. Int. Pl. Propag. Soc., 5: 47-50
- Waxman, S., 1957. The development of woody plants as affected by photoperiodic treatments. PhD Thesis, Cornell University, Ithaca, New York. Cited in ADAS Q Rev. (1977) 25: 41-62. The effects of photoperiod on rooting and growth of hardy ornamentals, D. N. Whalley, GCRI
- Waxman, S., 1965. Photoperiodic treatment and its influence on rooting and survival of cuttings 'Lighting under mist'. Proc. Int. Pl. Propag. Soc., 15: 94-7
- Whalley, D.N. and Cockshull, K.E., 1972. Some effects of photoperiod on the rooting of cuttings. Nursery and Garden Centre., 155: 138-9
- Whalley, D.N. and Cockshull, K.E., 1976. The photoperiodic control of rooting, growth and dormancy in *Cornus alba* L. Scientia Hort., 5: 127-38
- Willoughby, I., Clay, D. and Dixon, F., 2003. The effect of pre-emergent herbicides on germination and early growth of broadleaved species used for direct seeding. Forestry 76: 83-94
- Willoughby, I., Dixon, F.L., Clay, D. and Jinks, R.L., 2007. Tolerance of broadleaved tree and shrub seedlings to pre-emergence herbicides. Forestry 34:1-12

International Plant Propagators' Society case studies

Other sources of information

- Fairweather, P., 2000. IPPS Yearbook. A fragrant obsession
- Upson, T. and Andrews, S., 2008. The Genus *Lavandula.* IPPS Grafting Workshop

Appendix IV – Glossary of terms

Air-filled porosity (AFP) – a measure of the air space within a growing medium.

Apical cutting – a cutting with an intact shoot tip.

Bud wood – shoots from which buds for budding are prepared.

Carbohydrate – organic compounds comprising carbon, hydrogen and oxygen, which are important in metabolism and energy storage. In plants, sugars and starches are responsible for energy storage and cellulose is the structural building block; these compounds are formed during photosynthesis.

Clone – the vegetatively produced progeny of a single plant.

Controlled release fertiliser (CRF) – fertiliser products from which nutrient release is determined by temperature and moisture levels to provide a release of nutrients to match plant growth.

Day neutral plants – plants for which day length has no effect on flowering.

'Dry fog' – refers to fog in which a large proportion of the fine water droplets are small enough to remain suspended in the air for a relatively long time. It can, therefore, maintain a high level of humidity in the propagation environment with relatively little wetting of the growing medium, cuttings and other surfaces.

Dry weight – a measure of photosynthetic growth widely used when assessing trials work.

Fog – a term used to describe a mass of droplets of condensed water vapour suspended in the air and used for high humidity propagation. It differs from mist in that the water droplets from fog remain in suspension for a longer period than mist.

Grafting – the preparing and joining of plant parts (scion and rootstock) so that they may grow together.

Lignification – the natural plant process by which soft stems ripen and become hard and woody.

Liner – a young, well-rooted plant propagated in either a large cell, small pot or the open ground and suitable for growing on to saleable size, either in pots or the open ground. Typically, pot liners are produced in 7, 8 or 9 cm size containers. In its broadest sense, the term liner can mean anything from a seedling in a module to a tree whip.

Long day plants – plants for which night-break lighting or day length extension stimulates flowering.

Mist – a term used to describe a mass of water droplets in the air that are not generally suspended like the finer water droplets found in fog.

Photoperiod – the relative length of day and night.

Photosynthesis – the process by which plants use light to convert carbon dioxide and water into carbohydrates, so providing the energy and building blocks that plants require to survive, propagate and grow.

Potential evapotranspiration (ETp) – a rate at which a crop would lose water under prevailing environmental conditions if the water supply was non-limiting. It includes evaporation from the plant (transpiration) and from the soil or growing medium in the pot. This can be expressed as a quantity of water lost over time, by weight, volume or mm of water per 24 hours.

Pre-branched cutting – a cutting that has formed secondary laterals while still attached to the plant.

Relative humidity (RH) – a measure of the water vapour present in the air, expressed as a percentage of that which would be present if the air was saturated and at the same temperature.

Respiration – the process by which energy is released from carbohydrates in the plant, during which oxygen is taken up and carbon dioxide given off.

Rootstock – the root bearing plant on which a scion or bud is grafted or budded.

Scion – the part of a plant used for grafting onto a rootstock.

Scion wood – shoots from which scions are cut.

Short day plants – plants for which night-break lighting or day length extension inhibit flowering.

Stomata – small pore-like openings, mainly on the underside of the leaf, which are able to open and close, so providing a means of regulating carbon dioxide, oxygen and water vapour uptake and loss, as appropriate.

Tipping – a form of light pruning, whereby the apical tip is removed from a shoot or cutting.

Top-working – the grafting of a scion onto a long upright stem to create a particular plant habit.

Transpiration – the loss of water by evaporation via the stomatal openings on the leaf surface.

Understock – a term sometimes used instead of rootstock.

Vapour pressure deficit (VPD) – a measure of how far the air is from being saturated with water vapour. It is measured in units of pressure because the vapour pressure of water in air is a convenient measurement of its concentration.

'Wet fog' – fog with a relatively high proportion of water droplets that are large enough to fall out rapidly.

Worked – a term commonly used to describe plants propagated by budding or grafting.

Acknowledgements

The development of this guide would not have been possible without the contributions of many others within the HNS industry, to whom AHDB Horticulture is grateful. In particular, thanks go to the following people for their time and technical expertise throughout the preparation and writing of the Hardy Nursery Stock Propagation Guide:

Alastair Hazell, Darby Nursery Stock Ltd

Bill Godfrey, W Godfrey and Sons Ltd

Brian Howard (Dr)

Brian Humphrey, OBE

Chris Burgess, CB Consultant Agronomist

Chris Lane, Witch Hazel Nursery

David Hide, Walberton Nursery

David Millais, Millais Nurseries

David Talbot, ADAS

Dennis Fordham

Geoff De La Cour-Baker, Palmstead Nurseries Ltd

John Atwood, ADAS

John Buxton (Dr), ADAS

John Cooley, Proptek

Karl O'Neill, The Bransford Webbs Plant Company

Lee Woodcock, Palmstead Nurseries Ltd

Margaret Scott, MBE

Mark Howard, John Woods Nurseries Ltd

Mike Norris, New Place Nurseries Ltd

Neal Wright, Micropropagation Services Ltd

Neil Alcock, Seiont Nurseries

Nick Dunn, Frank P Matthews Ltd

Nick Reese, Jackdaws' Field Nursery

Paul Howling, Howard Nurseries Ltd

Paul McKarry, P&S Nursery Stock

Peter Bingham, Kingfisher Nursery

Peter van Delft, West End Nurseries

Phillip MacMillan Browse

Richard Harrison Murray, RHM Science

Stephanie Dunn James, Frank P Mathews Ltd

Photographic and image credits

Page	Image	Source
Cover	*Griselinia* plug plant	New Place Nurseries – Newey Group Perennial Plugs and Liners
	Propagation management	
7	Mechanical lift	West End Nurseries
7	Mobile benching	West End Nurseries
8	Fog/mist system in the propagation unit	Palmstead Nurseries Ltd
8	Shade screens	Palmstead Nurseries Ltd
11	Container-grown stock plants	Palmstead Nurseries Ltd
12	Field-grown stock plants	ADAS
12	Stock plants on raised beds	ADAS
14	Shade provision over evergreen stock plants	ADAS
14	Stock plants grown under protection	ADAS
16	Alpine stock plants	Palmstead Nurseries Ltd
21	Stock plant material for cuttings	ADAS
22	Cuttings in a cool box	ADAS
22	Cutting insertion	ADAS
23	Cutting insertion team	ADAS
24	Cutting insertion into preformed plugs	ADAS
24	Snips and cutting material	ADAS
28	Single slice wound	David Hide, Walberton Nursery
28	Incision wounding	David Hide, Walberton Nursery
28	Split wounding	David Hide, Walberton Nursery
31	Root constriction	Proptek
35	Effect of controlled release fertiliser in the media	ADAS
35	Benefits of controlled release fertiliser with bark	ADAS
	Propagation techniques	
41	Seed store	ADAS
42	Seed beds	Dennis Fordham
42	Seed sowing in drills	Dennis Fordham
43	Powdery mildew on *Acer*	ADAS
44	Seed sowing in trays	Dennis Fordham
45	Vermiculite cover over seed trays	Dennis Fordham
45	Deep rooting modules	Dennis Fordham
46	Stem section and cuttings	David Hide, Walberton Nursery
47	Nodal tip cutting	David Hide, Walberton Nursery
47	Internodal cutting	David Hide, Walberton Nursery
47	Heel cutting	David Hide, Walberton Nursery
48	Basal cutting	David Hide, Walberton Nursery
48	Softwood cutting	David Hide, Walberton Nursery
49	Semi-ripe cutting	David Hide, Walberton Nursery
49	Softwood and semi-ripe cuttings	New Place Nurseries Ltd
50	Cuttings for fruit tree rootstock production	Nick Dunn
50	Hardwood cutting alongside secateurs	David Hide, Walberton Nursery
51	Leaf-bud cutting	David Hide, Walberton Nursery
51	Root cuttings in a tray	ADAS
52	*Acanthus* in a plug tray	Howard Nurseries Ltd
53	Multiplication of stock during micropropagation	Walberton Nursery
54	Jars of plant material	Micropropagation Services Ltd
55	Plantlets under fleece	Seiont Nurseries

Page	Image	Source
55	Micropropagated *Heuchera*	Seiont Nurseries
56	Multiplication of stock during micropropagation	Micropropagation Services Ltd
57	Individual *Heuchera* plug	Seiont Nurseries
58	Budding and grafting knives	Nick Dunn
59	Bud patch on rose	David Austin Roses
59	Polythene budding tape	John Richards Nurseries Ltd
60	Potted rootstocks	John Richards Nurseries Lltd
60	Field-grown stock plant	Nick Dunn
61	Rootstock and scion	AHDB
61	Scion wood in store	Nick Dunn
63	Grafted *Quercus*	AHDB
64	Whip/splice graft	Nick Dunn
65	Side veneer graft	Nick Dunn
66	Modified side veneer graft – rootstock tongue	Nick Dunn
66	Modified side veneer graft being tied up	Nick Dunn
66	Completed whip and tongue graft	Nick Dunn
67	Making the required cuts in the 'T' budding process	David Austin Roses
68	Bud selection	David Austin Roses
68	Close-up of bud and shield	David Austin Roses
68	Bud insertion into rootstock	David Austin Roses
68	Bud patch	David Austin Roses
68	Bud patch degradation	David Austin Roses
69	Final union	David Austin Roses
69	Rootstock cuts in the chip budding process	Nick Dunn
69	Bud in position in rootstock	Nick Dunn
64-69	Grafting and budding illustrations	Stephanie Dunn James and Frank P. Matthews Ltd.
70	Chip bud tied in	Nick Dunn
70	Chip bud on container-grown rootstock	Nick Dunn
71	Tray of bare-root grafts	Nick Dunn
71	Bare-root grafts being laid out	Nick Dunn
71	Grafts in position for hot water callusing	Nick Dunn
72	Heat placement on grafts	Nick Dunn
73	*Iris* splits awaiting potting	Howard Nurseries Ltd
74	Stool beds	Nick Dunn
75	Close-up of stool bed	Nick Dunn
Propagation environments and systems		
79	Shade over polythene tents	ADAS
83	Basal heat from heating cables	ADAS
83	Basal heat from piped hot water	ADAS
83	Bed mist systems	New Place Nurseries Ltd
86	Evaposensor unit	New Place Nurseries Ltd
89	Polythene tent over cuttings	ADAS
89	Contact polythene over cuttings	ADAS
91	Sun tunnels	MAFF, now Defra
94	Root development on cuttings in a heated bin	Nick Dunn
95	Direct struck *Prunus*	Palmstead Nurseries Ltd
Aftercare		
96	Sciarid fly larvae on stem base	ADAS
98	*Neoseiulus cucumeris*	ADAS
99	Sciarid fly larva	ADAS
99	Adult sciarid fly	ADAS

Page	Image	Source
99	Adult *Hypoaspis*	ADAS
100	*Atheta coriaria*	Syngenta Bioline Ltd
100	Water snail	ADAS
101	Western flower thrips	ADAS
101	Two-spotted spider mites	ADAS
102	Vine weevil larvae	ADAS
102	Adult whitefly	ADAS
103	*Botrytis*	Palmstead Nurseries Ltd
103	Weeds along bed edge	ADAS
104	Loose-fill mulch	New Place Nurseries Ltd
105	Tray mat	Engro BV
108	Seed bed *Quercus*	AHDB
110	Plug medium with controlled release fertiliser	ADAS
111	Trays of rooted cuttings	ADAS
111	Cuttings with and without liquid feeding	ADAS
113	Crop trimming	The Bransford Webb Plant Company
115	Lit growth chamber	Micropropagation Services Ltd
117	Frost damage	Dove Associates
118	Root development in a plug	Proptek
121	Capillary sand bed	ADAS
122	Pre-branched *Photinia* cuttings	Palmstead Nurseries Ltd
International Plant Propagators' Society case studies		
124	Grafted *Hibiscus*	ADAS
125	Lavender stock plant	David Hide, Walberton Nursery
125	Internodal softwood tip cuttings of lavender	David Hide, Walberton Nursery
126	Lavender cuttings under a polythene tent	David Hide, Walberton Nursery
126	Rooted lavender cuttings in a plug tray	David Hide, Walberton Nursery
127	*Azalea* and *Rhododendron* cuttings under a polythene tent	David Millais
128	*Hebe* plug	The Bransford Webb Plant Company
129	Finished *Hebe* plant	The Bransford Webb Plant Company
131	On-site testing	Tim Pettitt
132	Moss and liverwort control	AHDB
132	Cold store	AHDB

Produced for you by:

AHDB Horticulture
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T 024 7669 2051
E comms@ahdb.org.uk
W horticulture.ahdb.org.uk
@AHDB_Hort

30004 0422