PLANT QUALITY

A Key to Success in Forest Establishment

Edited by Lauren MacLennan and John Fennessy

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Foreword

While the substantial programmes of upland afforestation carried out by the state sector in the 1960s, 1970s and early 1980s have declined in recent years, afforestation by the private sector has grown rapidly since the mid 1980s. In addition, reforestation by Coillte is now running at some 8000 ha annually. At the same time, changes in forest policy and regulation, and an increase in the availability of better quality lowland sites for forestry development, have resulted in changed species and provenance demands, all of which impinge directly on plant production and procurement.

Such changes in demand, allied to other developments such as increasing mechanisation of planting, and more broadleaves being planted, give rise to a need for new approaches and techniques. From its foundation COFORD has been involved in such developments, and, in co-operation with the nursery, sector has funded a wide range of research on many aspects of plant production: from seed, to nursery practice, to cold storage and handling and on-site storage. This investment has paid dividends for both the nursery sector and planting programme, and has contributed to maintaining annual production at 70-75 million plants.

To communicate the results of this research, and other developments, COFORD assembled a group of scientists involved in the funded research programme, international colleagues, and practitioners and policy makers. The well-attended event, held over two days, 20 and 21 September 2005, addressed issues from the perspective of both the planting stock producer and those involved in plantation establishment and regeneration. Other important aspects, such the underlying genetic quality and composition of planting stock were also addressed in depth.

All of the presentations at the event have been complied in this COFORD publication, which has been edited by Lauren MacLennan and John Fennessy – the conference organisers.

There is a great deal of information in the volume that will be useful to the nursery trade and those involved in plantation establishment. Important underlying issues, such as genetic quality and provenance, are also addressed. It is a volume that will be an important reference source, as well as a useful benchmark of current thinking on issues such as species selection, plant quality control, seed procurement and quality, and general nursery practice.

In conclusion, we wish to thank all those involved in organising the event, and Coillte Nurseries and None-so-Hardy Limited for their support over the course of the conference.

David Nevins (Chairman)

Dr Eugene Hendrick (Director)

Brollach

Cé go bhfuil na cláir substainteach do choillteoireacht thalamh ard bainte amach ag an rannóg stáit sna 1960í, 1970í agus luaithe sna 1980í tar éis meath le roinnt blianta anuas, tá coillteoireacht an rannóg phríobháideach tar éis fás go tapaigh ó lár na 1980í. Chomh maith le sin, tá athchoilltiú á dhéanamh ag Coillte ag nach mór 8000 heicteár in aghaidh na bliana. Ag an am céanna, tá éilimh ar speiceas athruithe agus dualfhoinse tar éis bheith mar thoradh ar athruithe i bpolasaithe agus rialacha foraoise, agus méadú ar infhaighteacht talamh íseal ar cháilíocht níos fearr le haghaidh forbairt foraoiseachta, téann siad seo ar fad in aghaidh táirgeadh agus soláthar plandaí.

Cruthaíonn a leithéid do athruithe ar éileamh, i dteannta forbairtí eile ar nós méadú i meicniú plandála, agus níos mó plandaí leathanduilleach á phlandáil, an gá do chur chuige agus teicníochtaí nua. Óna bhunú tá COFORD tar éis bheith páirteach in a leithéid de fhorbairtí, agus, i gcomhoibriú leis an rannóg plandlanna tá sé tar éis maoiniú a dhéanamh ar réimse leathan taighde ar go leor gnéithe do tháirgeadh plandaí: ó síol, go cleachtadh plandlainne, go stóráil fuar agus láimhseáil agus stóráil ar shuíomh. Tá an infheistíocht seo tar éis díbhinní a íoc don rannóg phlandlanna agus don chlár phlandála araon, agus tá sé tar éis ranníocaíocht a dhéanamh chun an táirgeadh bliantúil a choimeád ag 70-75 milliún planda.

Chun torthaí an taighde seo agus forbairtí eile a iompar, cuireadh COFORD grúpa eolaithe a bhí páirteach sa chlár taighde maoinithe, comhghleacaithe idirnáisiúnta, agus cleachtóirí agus déantóirí polasaithe le chéile. Rinne an ócáid, a fhreastail a lán daoine ar agus a raibh ar siúl ar feadh dhá lá, an 20 agus 21 Meán Fómhair, tagairt ar saincheisteanna ó thaobh táirgeoir stoic a phlandáil agus ó thaobh na daoine a raibh páirteach i mbunú agus athghiniúint plandáil Rinne siad tagairt chomh maith ar ghnéithe tábhachtacha eile, cosúil leis an cáilíocht bungéinitheach agus comhdhéanamh stoic plandála.

Tá na taispeántais go léir a bhí ag an ócáid curtha le chéile sa foilseacháin COFORD seo a bhfuil curtha in eagar ag Lauren MacLennan agus John Fennessy – eagraí an comhdháil.

Tá ana chuid eolais sa himleabhar a bheidh úsáideach don trádáil plandlainne agus do dhaoine a bhfuil páirteach i mbunú plandáil. Rinneadh tagairt ar bhuncheisteanna tábhachtach, cosúil le cáilíocht géiniteach agus dualfhoinse, chomh maith. Beidh an imleabhar mar fhoinse tagairt tábhachtach, chomh maith le marc airde úsáideach ar smaointí ar cheisteanna cosúil le roghnú speiceas, rialú cáilíochta planda, soláthar síolta agus cleachtadh plandlainne ginearálta agus cáilíocht.

I gconclúid, ba mhaith linn ár mbuíochas a ghabhail le gach duine a bhí páirteach in san ócáid a eagrú, agus Plandlanna Coillte agus None-so-Hardy Teoranta i gcomhair a chuid tacaíocht thar dul ar aghaidh an comhdháil.

David Nevins (Cathaoirleach)

Dr Eugene Hendrick (Stiúrthóir)

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Applying the target plant concept to nursery stock quality

Thomas D. Landis and R. Kasten Dumroese

ABSTRACT

The basic tenet of the target plant concept is that the quality of nursery stock is determined by outplanting performance (survival and growth), rather than characteristics or standards measured at the nursery. This means that there is no all-purpose plant, but that each outplanting project will require different species and stock types. In this paper, we discuss the six basic questions that help define the target plant:

1) What is the project objective?
2) Which species is appropriate and should local or genetically-improved seeds be used?
3) What factors limit survival and growth on the outplanting site?
4) When will the nursery stock be outplanted?
5) How will they be outplanted?
6) What is the ideal stocktype?

The target plant concept is a cyclic, continual process as outplanting site performance is used to update target plant specifications.

WHAT IS NURSERY PLANT QUALITY?

The first attempts to describe an ideal plant always start with morphological characteristics, such as shoot height and stem diameter, which are then converted into grading standards. In the southeastern USA, the classic research of Phil Wakeley resulted in three grades of nursery stock for the major southern pine species. His studies on the ideal pine seedling, however, convinced him that physiological aspects of plant quality were just as important as morphological characteristics (Wakeley 1954). In the last 25 years, research into seedling physiology has revolutionized traditional concepts of reforestation and restoration. This new research helped develop the target plant concept (Rose et al. 1990).

One of the basic tenets of the target plant concept is that quality is determined by survival and growth on the outplanting site. Nursery stock quality depends on how the plants will be used, and the best definition that we have found is ‘fitness for purpose’ (Ritchie 1984). This means that seedling quality cannot be merely described at the nursery, it can only be proven on the outplanting site. There is no such thing as ‘all-purpose’ nursery stock. A nice looking plant in the nursery will not survive and grow well on all sites. In the western USA, we talk about prescriptions for reforestation sites in which the forester plans what species and stock type should be used. Several states have ‘Free-to-Grow’ requirements which stipulate that outplanted nursery stock must not only be alive, but must have grown above the competing vegetation within five years.

DEFINING THE TARGET PLANT

A target plant has been cultured to survive and grow on a specific outplanting site, and can be defined in six sequential steps (Figure 1).

1. Objectives of outplanting project

The way in which nursery stock will be used has a critical influence on the characteristics of the target plant. Typically, reforestation after harvest uses commercially valuable tree species that may have been genetically-improved for fast growth are outplanted with the ultimate objective of producing saw logs or pulp. The target plant for restoration projects can be radically different. For example, a watershed protection project would require riparian trees and shrubs and wetland plants that will not be harvested for any commercial product. Restoration after wildfire can involve several target plant materials. On commercial forestlands, native grass seeds are sown to stop erosion and then tree seedlings are outplanted to bring the land back to full productivity as soon as possible.

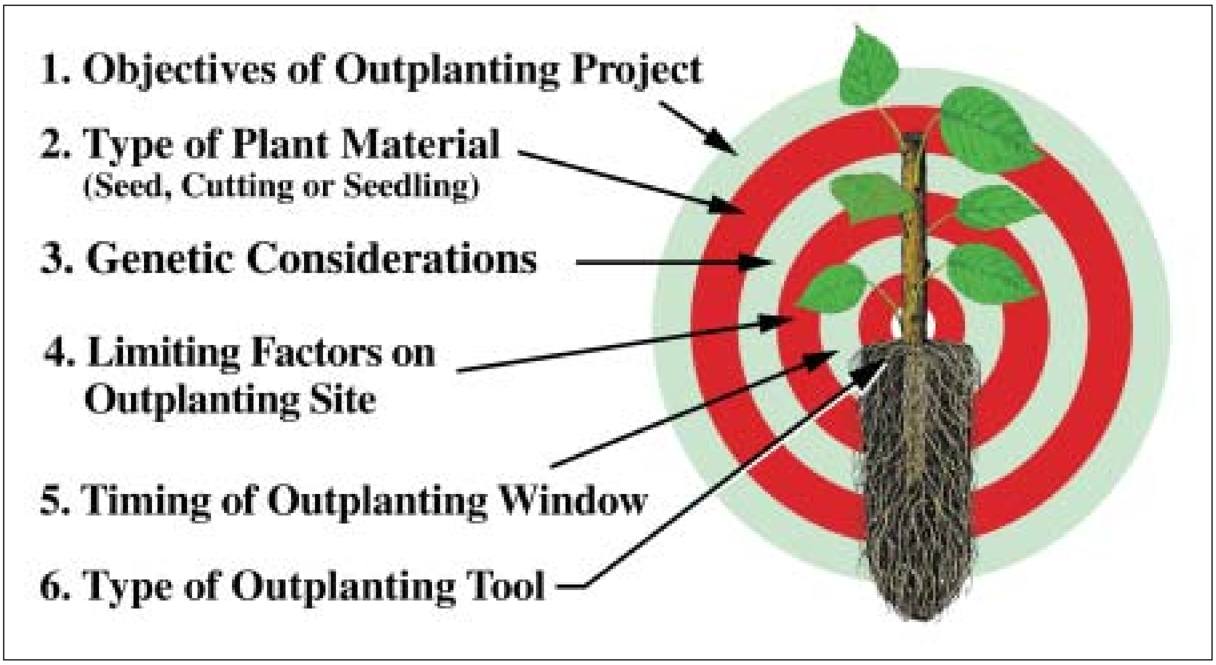

Figure 1: The target plant concept can be described in six sequential steps.

Creating habitat for threatened or endangered plants and animals, such as the Ivory-billed Woodpecker, is yet another project objective. This, the largest North American woodpecker, was thought extinct until last year when a confirmed sighting was made in a remote area of Arkansas. The habitat of the Ivory-billed Woodpecker is swamp and bottomland hardwood forest, most of which has been logged or drained for agriculture. Conservation organizations have initiated tree planting to restore the hardwood forests that these large woodpeckers need for food and shelter.

2. Types of plant materials

Target plant materials include seeds and all the various nursery stock types, including rooted cuttings:

- **Seeds**. Although direct seeding is rarely used in the USA for reforestation, seeds of native grasses, forbs, and shrubs are direct sown for restoration. For example, the JH Stone nursery in southern Oregon is currently producing over 30 species of native grasses and forbs. Seeds of commercial cultivars have been used in restoration projects for decades, but only recently have reliable supplies of source-identified, locally-adapted native seeds been available.
- **Seedlings and transplants.** Nurseries are currently producing a wide variety of plant stocktypes. In the southeastern USA, the 1+0 seedling is most common but western nurseries grow a variety of seedling and transplant stocktypes. During the 1960s, forest nurseries began to switch to seedlings because of the high labor cost of transplanting. Precision sowing created ideal seedbed density and root culturing produced seedlings with vigorous root systems and thick stem diameter. In the last 10 to 15 years, however, transplants have returned to favor because of the demand for a large vigorous seedling that can compete with vegetation on outplanting sites and meet ‘Free-To-Grow’ reforestation requirements (Landis and Scholtes 2003). The newest stocktypes are container-to-bare-root transplants in which small volume container seedlings are transplanted into bare-root beds for another year of growth. Seedlings grown in containers filled with stabilized media can be transplanted even earlier, making possible a one-year container transplant.
- **Rooted cuttings**. Some plants, notably *Salix* (L.) and *Populus* (L.), are most easily propagated by rooting cuttings. Demand for willow and cottonwood species has become more common in the last decade because of an increased interest in riparian restoration.

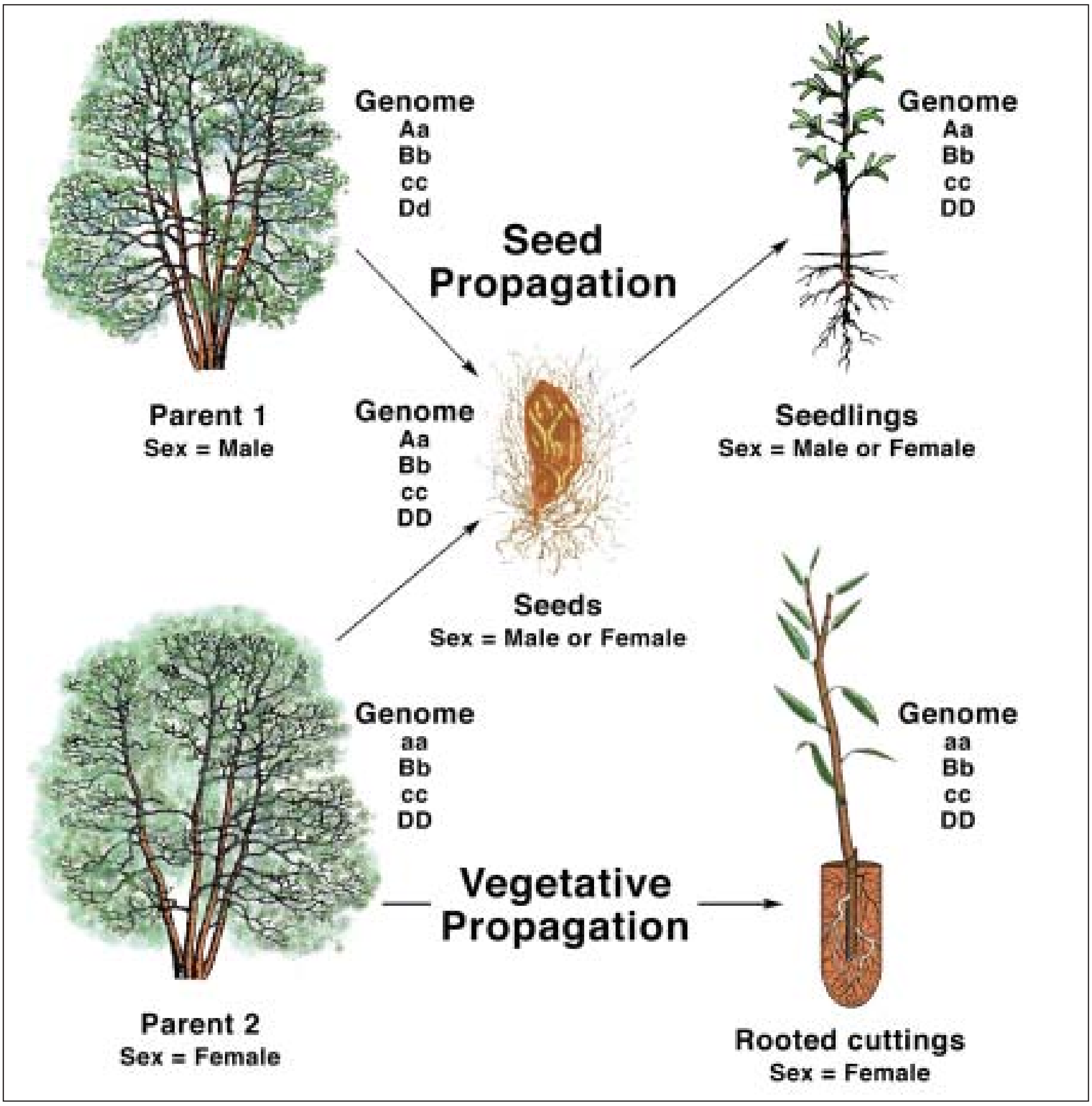

Figure 2: The target plant concept must consider whether plants were propagated by seeds or by cuttings because the choice will affect both genetic and sexual diversity.

There are drawbacks to vegetative propagation, however. Sexual propagation results in a mixture of genetic characteristics so that the offspring contain both male and female plants. On the other hand, asexual propagation methods produce exact clones of the mother plant. This is of particular concern with dioecious plants, such as willows and cottonwoods, because all the progeny produced by vegetative propagation will have the same sex as their parent (Figure 2) (Landis et al. 2001).

3. Genetic considerations

The third component of the target plant concept is concerned with how well outplanted nursery stock will be adapted to the local environment. Selection of the proper species is the primary consideration. Ecologically dominant or commercially valuable trees are routinely chosen for traditional reforestation, although species with unique characteristics are sometimes preferred. In the mountains of the northwestern USA, for example, lodgepole pine (*Pinus contorta* var. *contorta* Engelm.) is prescribed for low areas known as frost pockets because of this species's extreme cold tolerance.

Although commercial forest plantations have traditionally been monocultures of the most valuable species, planting a mix of species is now being reconsidered. Multiple species plantings improve biodiversity and create habitat but can also have economic benefits. A recent economic analysis of a mixed plantation of Norway spruce (*Picea abies* L.) and beech (*Fagus sylvatica* L.) concluded that mixed outplantings are not only ecologically beneficial but can also be economically justified (Knoke et al. 2005).

Once the proper species have been selected, the next consideration is genetic adaptation. Seed source and seed zones are familiar terms to foresters. They know that plant species vary throughout their geographic range because they are adapted to local site conditions. Forest nurseries in the western USA grow plants by seed zone, which is a three-dimensional geographic area that is relatively similar in climate and soil type (Figure 3). On the other hand, local adaptation is not always considered in ornamental nurseries. For example, both native plant nurseries and ornamental nurseries grow Douglas fir [*Pseudotsuga menziesii* (Mirb. Franco)] seedlings but the former distinguish between ecotypes (e.g. variety glauca) and ornamental nurseries offer different cultivars (e.g. 'Carneflix Weeping') (Landis 2001). The same principles apply to plants that must be propagated vegetatively. Cuttings must be collected from near the outplanting site to make sure that they are properly adapted.

Seed source affects outplanting performance in a couple of ways: growth rate and cold tolerance. In general, plants grown from seeds collected from higher latitudes or elevations will grow slower but tend to be more cold hardy during the winter than those grown from seeds from lower elevations or more southern latitudes (St Clair and Johnson 2003). Therefore, it is prudent to always specify seeds or cuttings from the same geographic zone and elevation in which the seedlings are to be outplanted.

4. Limiting factors on the outplanting site

The fourth aspect of the target plant concept concerns the ecological 'principle of limiting factors'. The specifications of the target plant should be developed by identifying which environmental factors will be most limiting to survival and growth on that particular site (Figure 4). Moisture availability is the most common limiting factor but at higher elevations and latitudes, cold soils may be more of a restriction. On these sites, temperature measurements in the shallow rooting zone may not exceed 50°F (10°C) during the summer and

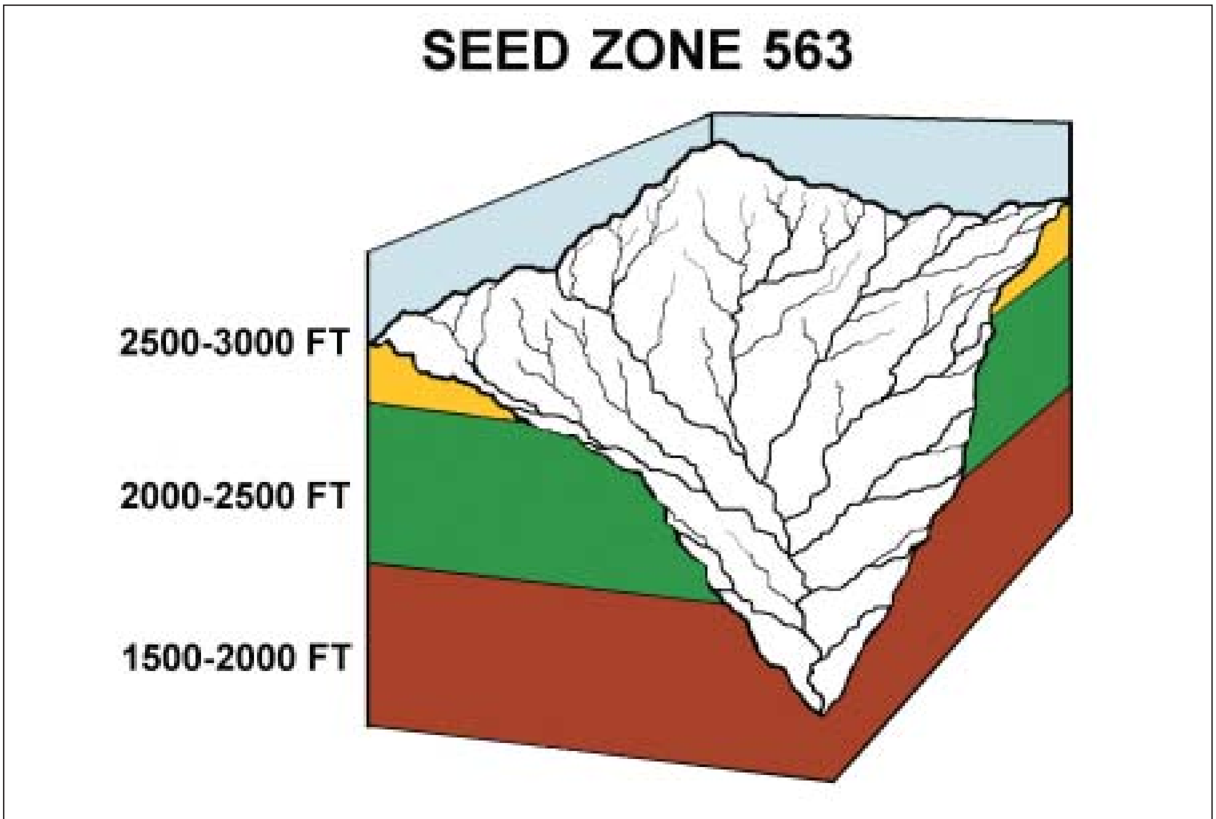

Figure 3: A seed zone is a geographic area that is relatively similar enough in climate and soil type and is described by a numerical code. In the mountainous western USA, seed zones are also stratified vertically by elevation bands.

research has shown that root growth almost stops completely below this temperature threshold. A reasonable target seedling for these sites would be grown in a relatively short container to take advantage of warm surface soils (Landis 1999). For high elevation reforestation sites in British Columbia, CANADA, Faliszewski (1998) concluded that the target seedling should be short with a compact root system.

One outplanting site condition deserves special mention — mycorrhizal fungi. Reforestation sites typically have an adequate complement of mycorrhizal fungi that quickly infect outplanted plants, whereas most afforestation and restoration sites do not. For example, severe forest fires or mining operations eliminate all soil micro-organisms including mycorrhizal fungi. Therefore, plants destined for these sites should receive inoculation with the appropriate fungal symbiont before outplanting. The timing of the inoculation must also be considered because many mycorrhizal fungi will not survive in the high nutrient environment of the nursery.

5. Timing of the outplanting window

The timing of the outplanting project is the fifth aspect of the target plant concept that should be considered. The outplanting window is the period of time in which environmental conditions on the outplanting site are most favorable for survival and growth. As mentioned in the previous section, soil moisture and temperature are the usual constraints. In the Pacific Northwest USA, plants are outplanted during the rains of winter or early spring; in the mountains of Mexico, however, outplanting is done during the summer rainy season. Soil temperature rather than moisture is the consideration at high elevations or latitudes, so container stock is outplanted in mid-summer or early autumn.

Container plants are uniquely suited to mid-summer and autumn outplanting because they can be artificially conditioned to withstand handling stresses (Figure 5). For example, autumn outplanting with containers on high elevation sites in northern California, USA has shown a 50 to 100% increase in stem volume compared to spring planting (Fredrickson 2003). Summer outplanting is a relatively new

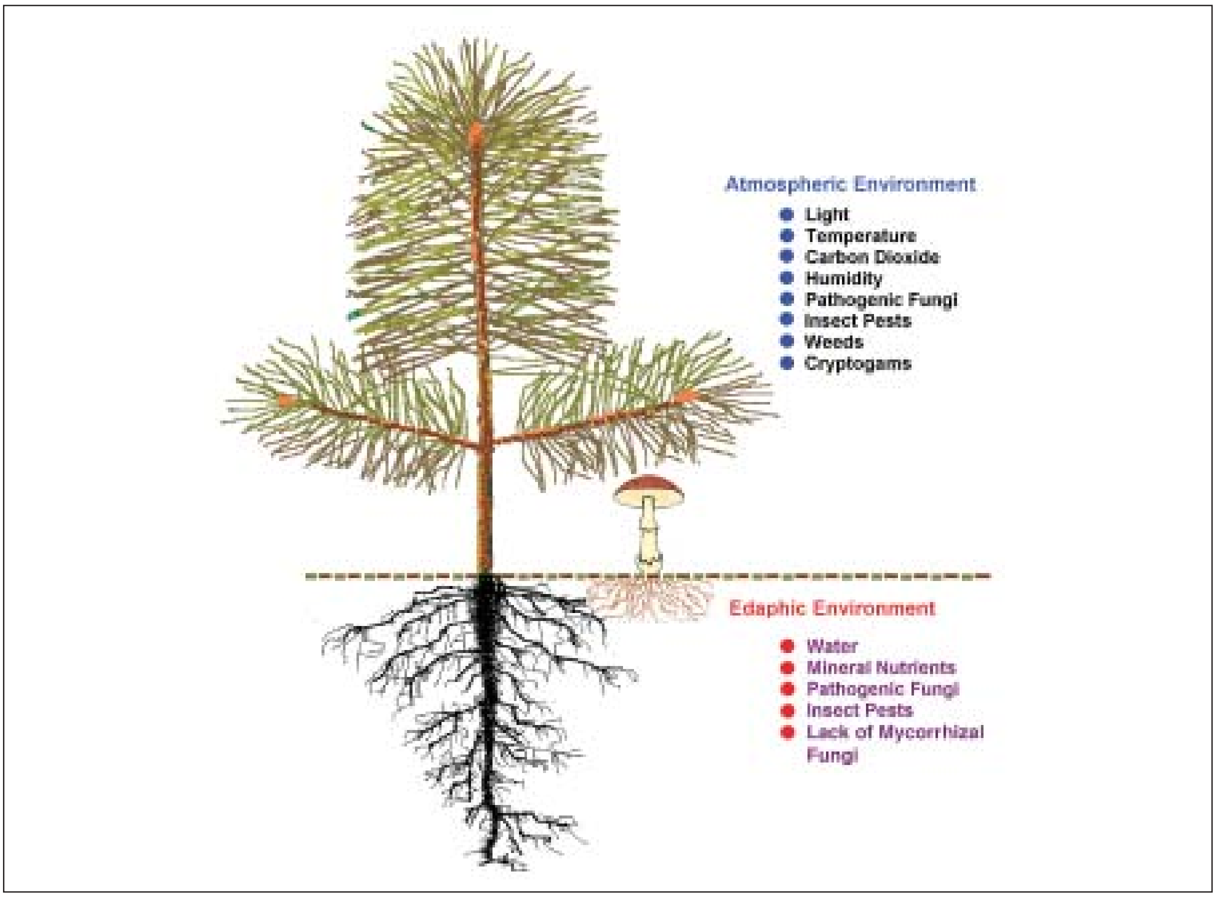

Figure 4: Defining the limiting factors on each project site is crucial to the target seedling concept.

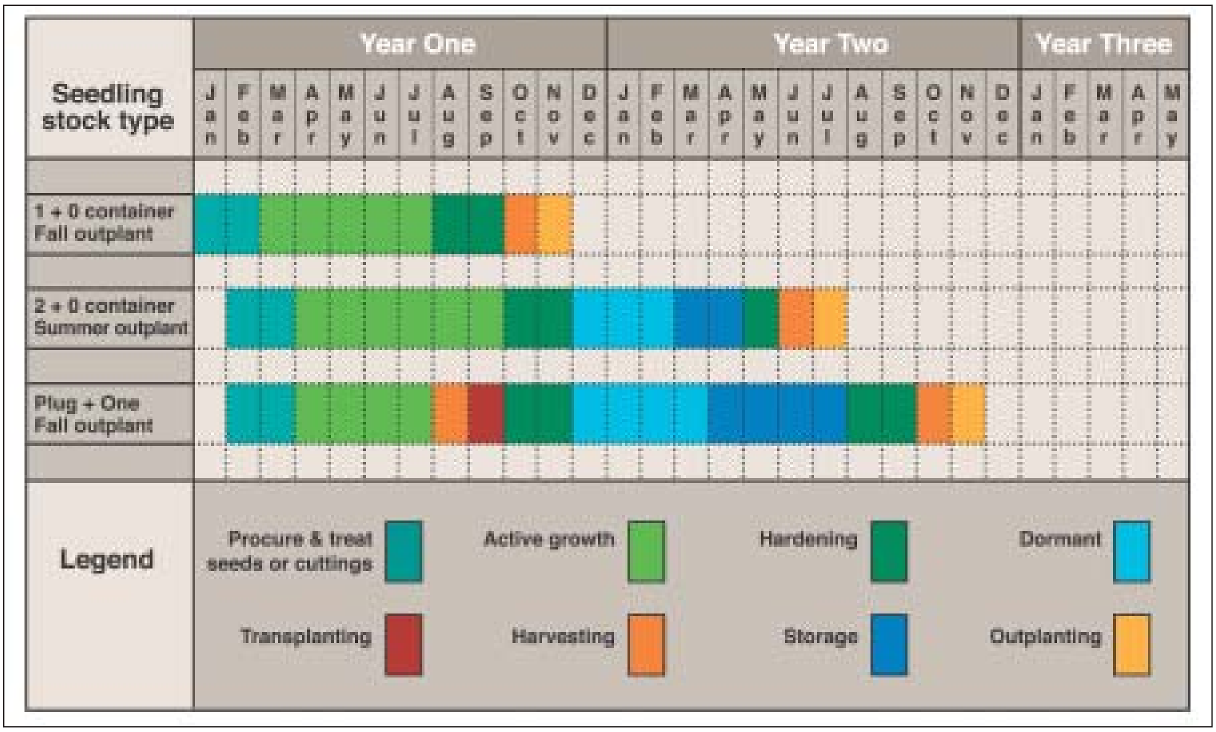

Figure 5: Summer and autumn outplanting are now possible for high elevation or high latitude sites, but the container stock is produced with special nursery production schedules that incorporate special conditioning.

practice that developed in the boreal regions of Canada (Revel et al. 1990) and has since found some application at high elevation sites in the Rocky Mountains of the USA (Page-Dumroese and Dumroese, unpublished data). Target plant characteristics are similar for both summer and autumn outplanting: hardened container stock with minimal handling and storage.

6.Outplanting tools and technique

A wide variety of hand outplanting tools have been used successfully (Lowman 1999), and therefore tools and outplanting techniques must be considered in the target seedling concept. All too often, foresters or restoration specialists develop a preference for a particular implement because it has worked well in the past. However, no one tool will perform well under all site conditions. Often, planters will choose the implement that gets plants into the ground as quickly as possible. This obsession with productivity is understandable but can be counterproductive. For example, the dibble was developed as an easy and quick way to outplant container seedlings. Experience has shown that dibbles work reasonably well on sandy soils but, in clay soils, they create a compacted soil layer that inhibits root egress.

Several machine planters are commercially available, but this equipment imposes unique restrictions because the target seedling must conform to the size and shape of the handling equipment. With tractor-drawn continuous furrow planting machines, nursery stock must have stem diameters that fit the holding clips on the planting wheel, and their root systems must not be longer than the depth of the furrow. Self-propelled spot planting machines were designed for container stock. For example, the Swedish Bracke planter has interchangeable magazines that will handle container plants with total heights of 50, 60, 70 mm (Stirling 2000). So, where mechanical planting is used, the target plant is more defined by the type of outplanting tool rather than any of the other factors.

The type of outplanting tool must be given special consideration when working with volunteers or other inexperienced planters. Many of these people do not have the skill or strength necessary to properly place plants on wildland sites. One option is to have a professional create planting holes with a machine auger and let the volunteers insert plants and tamp them into place. This technique has several benefits: the professional chooses the proper planting spot, creates the desired pattern, and makes certain that the planting hole is large and deep enough to avoid ‘J-roots’.

The pattern and spacing of outplanted seedlings is also a reflection of project objectives. Industrial forestry projects, where timber production is the primary objective, outplant the maximum number of trees per area in a regularly-spaced pattern (Figure 6A). The same technique is used for Christmas tree plantations where tree growth and form are the main concerns. Where ecological restoration is the objective, however, outplanting plants randomly (Figure 6B) or in random groups (Figure 6C) is more representative of natural vegetation patterns.

FIELD TESTING THE TARGET PLANT

One of the unique aspects of the target plant concept is that it is a collaboration between nursery managers and their customers. At the start of any planting project, the customer and the nursery manager must agree on certain morphological and physiological specifications. This prototype target plant is grown in the nursery and then verified by outplanting trials that monitor survival and growth for up to five years. The first few months are critical because nursery plants that die immediately after outplanting indicate a problem with stock quality. Plants that survive initially but gradually lose vigor indicates poor planting or drought conditions. Therefore, plots must be monitored during and at the end of the first year for initial survival. Subsequent checks after three or five years will give a good indication of plant growth potential. This performance information is then used to give valuable feedback to the nursery manager who can fine tune the target specifications for the next crop

As an example for the western USA, the Oregon State University Nursery Technology Cooperative is conducting outplanting trials of one-year-old stocktypes on two fire restoration sites in southwestern Oregon (Nursery Technology Cooperative 2005). The Timbered Rock site in the Cascade Mountains is much drier than the Biscuit fire in the Coast Range. In terms of survival, the Styroblock® container performed much better than the transplants at Timber Rock, whereas there was little difference on the wetter Biscuit site (Table 1). The container stocktype also grew much better at both sites, but especially so at the Timbered

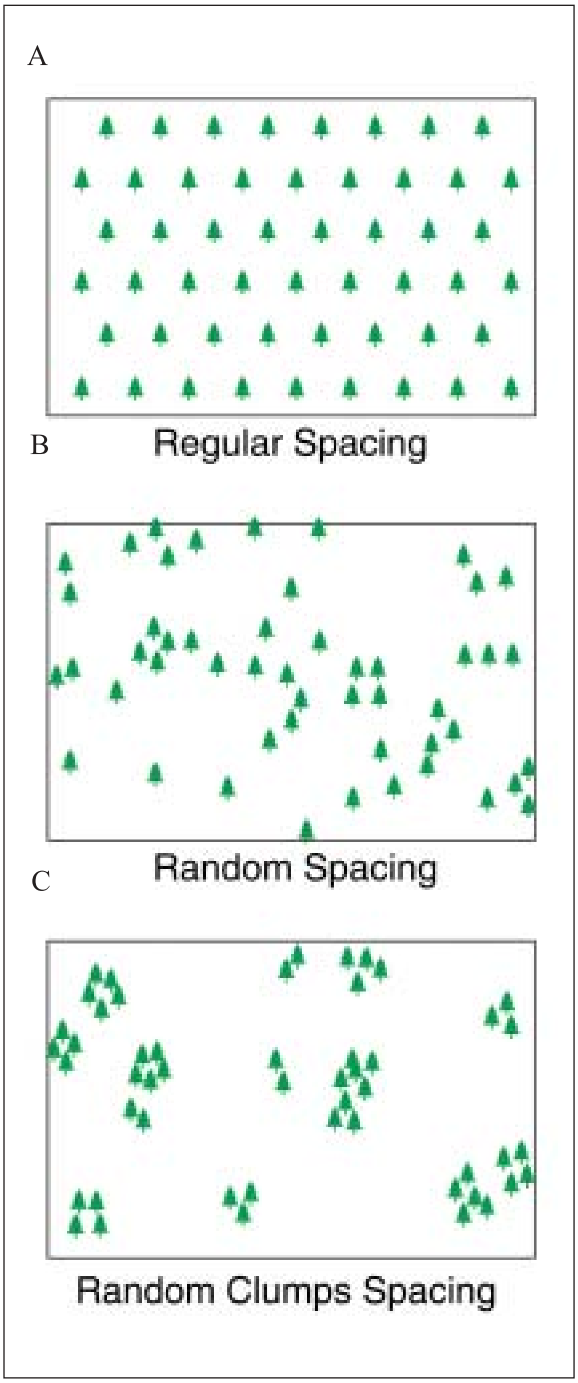

Figure 6: In addition to target seedling specifications, the objectives of the outplanting project also affect planting patterns. If the objective is rapid growth or Christmas trees, then the plants can be regularly-spaced (A). Most restoration projects want to avoid the 'cornfield look', however, and so plants are spaced in a more random pattern that would mimic natural conditions (B). The most natural outplanting look uses the random clumped pattern where different species are planted in groups (C).

Table 1: Outplanting performance of Douglas fir stock types on different outplanting sites after one growing season (Nursery Technology Cooperative 2005).

Stocktype	Survival (%)	Height Growth (cm)	Stem Diameter Growth (mm)
Timbered Rock Fire - Oregon Cascade Mountains			
1+1 Bare-root Transplant	14 c *	4.2 b	- 0.6 b
Q-Plug Container Transplant	39 b	2.6 b	- 0.3 b
Stryoblock® Container - 246 cc	87 a	12.0 a	0.8 a
Biscuit Fire - Oregon Coastal Mountains			
1+1 Bare-root Transplant	98 a	4.6 b	0.5 b
Q-Plug Container Transplant	98 a	7.0 a	0.5 b
Stryoblock® Container - 246 cc	99 a	7.5 a	1.1 a

* Within each site, means followed by the same letter are statistically different at the p ≤ 0.05 level

Rock site where grass competition was severe. In fact, the severe moisture stress caused by the grass resulted in a negative stem growth for the two transplant stocktypes.

CONCLUSIONS

Propagation of plants for afforestation, reforestation, or restoration is a cyclic operation. Similarly, the process of deciding upon, and growing, the best plants for a particular site should be a cyclic process between the land manager and the nursery. The target plant concept is a comprehensive, yet adjustable, system for producing the best nursery stock for any project. An ideal nursery plant, suitable for all purposes, does not exist. Instead, the ultimate use of the plants controls all aspects of the nursery programme. Nursery managers should grow the type of stock that is appropriate, rather than land managers having to use whatever the nursery produces. Key to this process is good communication. Nursery stock, grown using the target plant concept, are the result of field observations and the ultimate test of quality is outplanting performance. Thus, the target plant concept insures that the best possible quality stock will be outplanted and that subsequent survival and growth will be used for further improvements.

REFERENCES

B.C. Ministry of Forests. 1998. *Provincial seedling stock type selection and ordering guidelines*. Victoria, BC: Ministry of Forests, Forestry Division. 71 p.

Faliszewski, M. 1998. *Stock type selection for high elevation (ESSF) planting.* Forest Nursery Association of British Columbia meetings, proceedings, 1995, 1996, 1997:152.

Fredrickson, E. 2003. *Fall planting in Northern California.* In: Riley L.E., Dumroese R.K., Landis T.D. (technical coordinators). National Proceedings:Forest and Conservation Nursery Associations-2002. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-28: 159-161.

Knoke, T., Stimm, B., Ammer, C. and Moog, M. 2005. Mixed forests reconsidered: A forest economics contribution on an ecological concept. *Forest Ecology and Management* 213: 102-116.

Landis, T.D., Dreesen, D.R. and Dumroese, R.K. 2003. Sex and the single Salix: considerations for riparian restoration. *Native Plants Journal* 4(2):110-117.

Landis, T.D. 2001. *The target seedling concept: the first step in growing or ordering native plants.* In: Haase, D.L. and Rose, R. (eds). Native plant propagation and restoration strategies, proceedings of the conference. Corvallis, OR: Oregon State University, Nursery Technology Cooperative and Western Forestry and Conservation Association: 71-79.

Landis, T.D. 1999. *Seedling stock types for outplanting in Alaska.* In: Stocking standards and reforestation methods for Alaska. Agricultural and Forestry Experiment Station, Misc. Publication 99-8. Fairbanks, AK: University of Alaska Fairbanks: 78-84.

Landis, T.D. and Scholtes, J.R. 2003. *A history of transplanting.* In: Riley L.E., Dumroese R.K. and Landis, T.D. (technical coordinators). National Proceedings: Forest and Conservation Nursery Associations — 2002. Ogden, UT:

USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-28: 89–97.

Lowman, B. 1999. *Tree planting equipment.* In: Stocking standards and reforestation methods for Alaska. University of Alaska Fairbanks, Agricultural and Forestry Experiment Station, Misc. Publication 99-8: 74-77.

Nursery Technology Cooperative. 2005. *Rapid response reforestation: comparison of one-year-old stocktypes for fire restoration.* NTC Annual Report. Corvallis OR, Oregon State University, Department of Forest Science, Oregon State University: 23-27.

Ritchie, G.A. 1984. *Assessing seedling quality.* In: Duryea, M.L. and Landis, T.D. (eds). Forest Nursery Manual: Production of Bare-root Seedlings. Kluwer Academic Press. The Hague: 243-259.

Rose, R., Campbell, S.J. and Landis, T.D. 1990. *Target Seedling Symposium: Proceedings, Combined Meeting of the Western Forest Nursery Associations*. 1990 August 13-17; Roseburg, OR. Gen. Tech. Rep. RM-200. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 286 p.

Stirling, J. 2000. The Bracke mechanical planter could have a role to play in Canadian forestry. *Logging and Sawmilling Journal.* October 2005. Accessed on December 6, 2005 at: http://www.forestnet.com/archives/Oct_00/forestry.htm.

St Clair, B. and Johnson, R. 2003. *The structure of genetic variation and implications for the management of seed and planting stock.* In: Riley, L.E., Dumroese, R.K. and Landis, T.D. (technical coordinators). National Proceedings: Forest and Conservation Nursery Associations - 2003. Ogden (UT): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-33: 64-71.

Wakeley, P.C. 1954. *Planting the southern pines*. Agricultural Monograph No. 18. Washington, DC: USDA Forest Service. 233 p.

Reaping what you sow - Seeds and plant quality

Conor O'Reilly and Pat Doody

ABSTRACT

Germination problems in the nursery may lead to a reduction in the quality of the resulting plants and increase the length of the production cycle. Seed dormancy, handling and storage practices before sowing, date of sowing and moisture availability after sowing are probably the most important factors affecting seed germination in the nursery. The results of recent research have shown that dormancy can be broken more effectively in the seeds of many tree species using the target moisture content (TMC) method, which involves maintaining the moisture content (MC) of the seeds at a lower MC than the fully imbibed (FI) state (standard method) during chilling. The TMC seeds can be cold or freezer stored for more than a year with little effect on germination potential or reintroducing dormancy. Short periods of mild freezing or incubation at warm temperatures also may enhance germination in some species. Although the TMC method reduces the sensitivity of seeds to seedbed temperatures, it is preferable to schedule sowing operations to reflect the optimum temperature for germination in each species. Unlike the seeds of most other tree species, oak (*Quercus robur* L. and *Q. petraea* L.) acorns are difficult to store, even over one winter. The results of recent research has revealed that soaking acorns for five days before storage at -3°C improved germination and the yield of usable plants in the nursery compared with acorns that were stored in the standard way. The type or combination of bed coverings used may also influence seedbed temperature and soil moisture availability. Seeds covered with sand followed by grit may germinate better than seeds covered with grit only (standard method for most small-seeded species in Ireland). The use of cloches or mulches may improve germination further. Seedbeds should be irrigated with frequent light (mist) applications (especially alder and birch seeds) of water during dry periods.

INTRODUCTION

Seed[1] factors can have a large effect on the morphological quality of the plants derived from them. Low, slow, uneven and unreliable germination may lead to many of the following problems in the nursery:

- Difficulty in reaching target plant size dimensions
- Understocked or overstocked seedbeds
- Lack of uniformity in plant size
- Longer production cycle.

The end result is that the nursery manager may find it difficult to produce good quality seedlings, or the quality of the plants may not be consistent from year to year. Furthermore, it may be difficult to produce a sufficient number of good quality plants to make the operation economically viable. An example of the result of poor germination is shown in Figure 1.

After addressing soil condition and its suitability for growing a particular species, the next most important step in the production cycle

Figure 1. An example of poor and uneven germination in a seedbed in an Irish nursery.

[1] *The term seed is used for convenience throughout the text, although in reality the seed 'unit' may include part of the fruit (e.g. pericarp).*

in the nursery is to optimise seed germination. If seed germination is poor, then it is difficult to compensate for this using other cultural measures later in the growing cycle. For example, if the seedlings are small because the seeds germinated slowly or late in the season, additional fertiliser might be applied to compensate for this. Such an approach is unlikely to be successful and it is probably unsustainable in the long term.

Most of the effects of seed germination on plant quality are indirect. For example, too much germination (which might otherwise suggest a 'good' result) reduces quality, mostly through its effect on plant density. Too much germination usually occurs because of difficulties encountered in accurately predicting the exact level of germination (i.e. the implication of the 'field factor'). If germination is variable over several years in the nursery, then it is likely that the sowing rate will be adjusted to reflect this, so there is a risk of overstocking in some years.

Many pre-sowing and post-sowing factors influence seed germination in the nursery. The most important of these are examined in this paper, focussing primarily on the situation for bare-root nurseries. Pre-sowing factors include seed dormancy and seed quality, while post-sowing factors include soil temperature (date of sowing) and moisture availability. Most of the new information presented in this paper is based on the results of research carried out in the COFORD-funded QualiBroad project. Many diseases, insects, birds and other organisms and agents may also reduce germination in the nursery, but these topics are beyond the scope of this paper.

PRE-SOWING FACTORS

Seed quality and seed dormancy are the most important factors that influence germination in the nursery. Seed quality (as reflected in seed purity, weight, germination potential and vigour) must be accurately assessed so that the correct sowing rate can be calculated. The proportion of empty seeds also influences seed quality. However, since the quality of a seed lot can be assessed prior to sowing, adjustments can be made to the sowing rate to account for differences in quality. A seed lot of lower quality is normally sown more densely than a higher quality lot. However, only high quality lots (i.e. few empty seeds) might be used in a container nursery or for precision sowing operations in a bare-root nursery.

Seeds are normally stored from the time of harvesting until the time of sowing in the nursery, so their physiological quality may deteriorate during this period. Nevertheless, seeds of most tree species can be stored at cold temperatures for long periods, provided the moisture content (MC) of the seeds is kept below about 12%. Seeds that have such characteristics are known as 'orthodox' seeds. Such seed is normally highly dormant during storage (Gordon 1992b), so it must be pretreated to release dormancy before sowing. The type of pretreatment used, as well as its timing and duration, should be carefully determined for different species, to maximise seedling yields.

The seeds of some species are difficult to store and are classified as 'recalcitrant'. These include seed of *Aesculus, Araucaria, Castanea* and *Quercus* species. The nuts of common beech (*Fagus sylvatica* L.) are usually characterised as orthodox, although considered by some as intermediate (Gordon 1992b). Pedunculate (*Quercus robur* L.) and sessile (*Quercus petraea* L.) oak are the only species with recalcitrant storage characteristics that are of importance to Irish forestry.

The effects of the most important pre-sowing factors on germination potential are described separately for seeds that have orthodox and recalcitrant characteristics.

Orthodox species

It is important to ensure that seeds are handled, processed, and stored under close to ideal conditions so that quality is not compromised at any stage. Seed dormancy is the most important pre-sowing factor affecting germination potential and vigour. Furthermore, seeds that are fully released from dormancy are vulnerable to damage during handling and sowing operations (Tanaka 1984). Therefore, dormancy is also important because it affects the potential resistance of seeds to handling stresses.

<u>Seed dormancy</u>

Seed dormancy is defined as the ability of a seed to germinate under favourable environmental conditions. However, the seeds of many tree species also display conditional dormancy, which means that they do not germinate or they germinate poorly under certain environmental conditions. For example, alder (*Alnus glutinosa* (L.) Gaertn.) and downy birch (*Betula pubescens* Ehrh.) seed germinated readily at both low (15°C) and high (20/30°C) temperatures after been prechilled, but seeds that received short periods of chilling germinated poorly at the low temperature (Figure 2).

Seed dormancy is a complex mechanism in many tree species, especially in the broadleaves. It may be expressed through morphological or physiological mechanisms, or more commonly a combination of both. The hard outer seed coat (or surrounding tissues) is the most common (morphological) mechanism of seed dormancy, which restricts water uptake and gas exchange (Suszka et al. 1996b). Seed of most species can be readily softened in cold water, but more extreme measures may be required in others. Acids, hot water, 'hot wire' and various mechanical treatments may be used to soften the seed coat and/or surrounding tissues (Bonner 1987). Some species require warm temperature, or warm temperature alternating with cold temperature, to release dormancy (Suszka et al. 1996b). For example, seed of common ash (*Fraxinus exelsior* L.) (and some other species) requires a warm phase followed by a cold phase to break dormancy (Suszka et al. 1996b). Nevertheless, most tree species require some form of moist prechilling (sometimes called stratification) to release dormancy. The seed coat is usually softened during pretreatment.

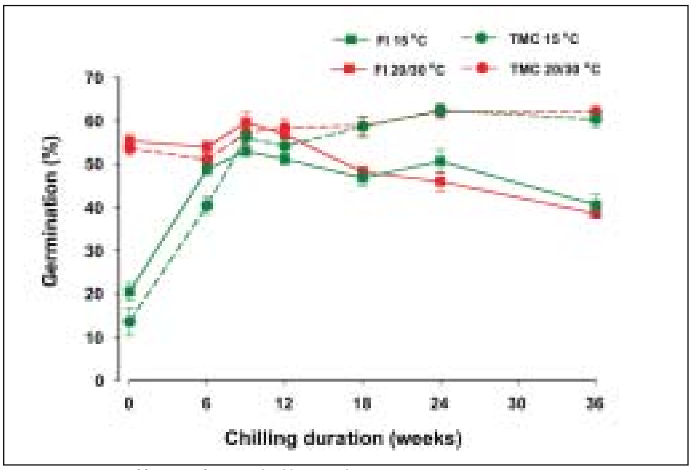

Figure 2. Effect of prechilling duration on percentage germination of alder seeds at 15°C or 20/30°C. The seeds were fully imbibed (FI) or adjusted to a target moisture content (TMC) level before chilling.

Prechilling to break dormancy

Provided seed is sown in the autumn or winter, dormancy can be broken naturally in the seedbed in response to natural chilling after sowing (Gordon 1992a). The response of seeds to natural fluctuating conditions varies, especially due to genetic factors, leading to huge variation in the time and level of germination. Although this might maximise the survival potential of a species in the wild, it may lead to poor, uneven and/or unreliable germination in the nursery. Losses due to vermin, diseases and other agents over the winter may exacerbate the problem. In addition, it is sometimes difficult to sow during the autumn and winter due to other constraints (e.g. adverse weather conditions or availability of seedbed space).

Seed of most species is chilled (usually 2-4°C) in the fully imbibed (FI) state for various periods to release dormancy, depending on the species and seed lot (Gordon 1992a). While dormancy will be broken more evenly using controlled, constant chilling temperatures, than under natural conditions, there will still be considerable variation in the response of seeds to chilling. Furthermore, seeds are prone to germinate prematurely or deteriorate if the period of chilling is extended. Adverse weather conditions and other factors frequently delay sowing in the nursery. Prematurely germinating seeds are also prone to damage during sowing operations, as discussed earlier. An alternative method is to use a lower or 'target' MC (TMC) level during chilling. Seeds are usually adjusted to TMC levels of 3-8 percentage points below the FI state, but it may be much lower than this in some species. Seed dormancy in many species is broken much more effectively using this method, but there are other important advantages. Seed adjusted to TMC levels can be held at chilling temperatures for lengthy periods without the risk of premature germination (Jensen 1996, De Atrip and O'Reilly 2005). The only potential disadvantage in using the TMC method is that the duration of the chilling period required to release dormancy is usually longer than for the standard FI method (thus increasing the length of the lead-in period needed for treatment).

The main findings of recent research on the use of the TMC method compared with

Table 1. Effect of standard fully imbibed (FI) versus TMC seed prechilling treatments on alder and birch seedling emergence (number m^{-2}) in Ballintemple Nursery.

Species	FI	TMC
Alder	827	865
Birch	183	500

the standard FI method in alder and birch are shown in Figure 2. Germination potential declined in the FI seeds as the period of prechilling was extended beyond about 8 weeks in alder and 12 weeks in birch. The results from a field experiment in birch confirmed that the TMC method resulted in better germination than the standard FI method (Table 1), but sowing was delayed, leading to a decline in the quality of the FI seeds during the extended chilling period. Germination varied less in alder, but a similar result might have been expected if sowing had been delayed also. Therefore, the TMC method is likely to deliver consistently reliable results in the nursery. Similar results have been reported for several other species (Downie et al. 1993, Jinks and Jones 1996, Poulsen 1996, Jensen 1997).

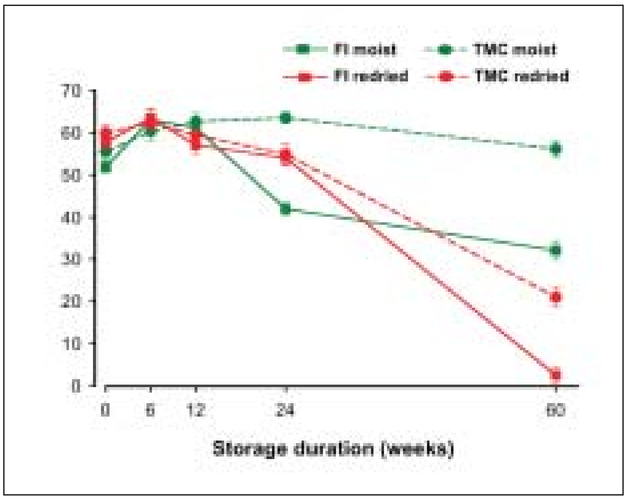

Figure 3. Percentage germination at 15°C of alder seeds after storage at -3°C for up to 60 weeks. Seeds were prechilled at fully imbibed (FI) or target moisture content (TMC) levels, after which they were stored moist or redried to <12% MC. Vertical bars are one standard error.

Temporary storage of prechilled seeds

While ‘orthodox’ seeds can be safely stored at normal refrigeration temperatures for long periods in the ‘dry’ (low seed MC) state, fully moist seeds may germinate prematurely or deteriorate quickly once dormancy has been released. Sowing delays, which frequently occur due to adverse weather or other reasons, may cause such problems. Many nurseries, including Coillte Nurseries, routinely use mild freezing temperatures (ca -3°C) to arrest germination and slow the rate of deterioration in FI seeds. Recent research on alder and birch seed confirmed the benefits of mild freezing (De Atrip and O'Reilly 2006a), as shown for alder in Figure 3. After prechilling, alder seeds were held at -3°C for up to 60 weeks in the moist or dry (re-dried to <12% MC before storage) state. All seed stored for up to 12 weeks with little impact on germination potential (compared with values at time of storage). The moist FI seed deteriorated after about 12 weeks at -3°C. There was a larger decline in germination in the redried seeds, but this was mainly due to a re-introduction of dormancy rather than a decline in quality (De Atrip and O'Reilly 2006a). However, the moist (not redried) TMC seeds could be safely stored for up to 60 weeks at -3°C (Figure 3). This gives additional flexibility in nursery operations, allowing TMC seed to be sown the following spring with no adverse effect on seed quality or risk of re-introducing dormancy.

Recalcitrant species

This section addresses storage and germination of penduncŭlate and sessile oak.

It is difficult to store acorns safely over more than one winter, so they are often sown in the autumn and allowed to break dormancy naturally in the seedbed (Gordon 1992a). Nevertheless, significant losses can occur over the winter (Aldous and Mason 1994), and it is often difficult to sow in the autumn due to poor weather conditions. Although dormancy is relatively weak in oak acorns (Suszka et al. 1996b), they are likely to germinate unevenly after autumn sowing. Therefore, it is usually necessary, and perhaps preferable, to store acorns for sowing in the late winter or spring.

The results of several studies have shown that the critical MC for storage of acorns is about 40%, below which viability declines rapidly (Suszka and Tylkowski 1980, Gosling 1989, Poulsen 1992). The usual method of short-term storage (over one winter) of oak acorns is to mix the seed in a medium (such as dry peat or sawdust) and place them in containers or sacks at ca 2-4°C (Gordon 1992b). Acorns can also be kept in cold-storage in containers (e.g. plastic bags) without a medium (Gosling 1989). However, Suszka (1996b) reported that oak acorns can be stored at -3°C for up to three years with only a modest decline in viability if they are maintained in a modified environment (high CO_2 and low O_2 concentrations). However, this method of storage is difficult to implement in practice, so it is not used widely. Furthermore, acorns should be treated (usually using hot water) prior to storage to reduce the risk of fungal damage (Suszka and Tylkowski 1980; Suszka et al. 1996b), but the risk may be low for acorns stored at freezing temperatures (Özbingöl and O'Reilly 2005). In Ireland, oak acorns (about 38-43% MC) are sown in the autumn or stored in Hessian bags at -3°C over one winter.

The results of recent research in the QualiBroad project revealed that acorn storability could be improved by soaking for five days before storage at -3°C, compared with standard method. Acorns that had the highest MC performed best in laboratory tests (Figure 4). The results of field experiments in 2004 confirmed that this method of seed pretreatment/storage improved germination and the yield of saleable plant in the nursery bed (Table 2).

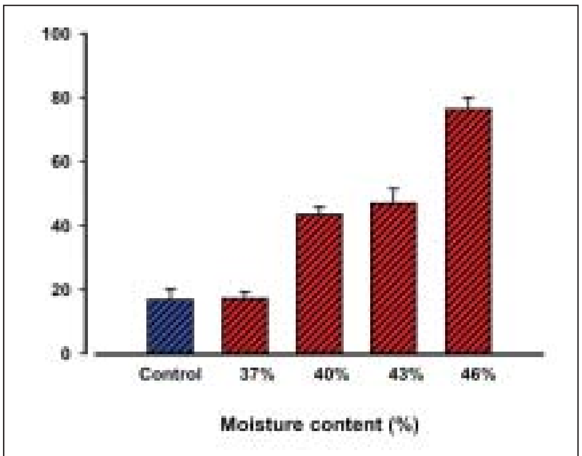

Figure 4. Effect of freezing storage for six months on the germination of oak acorns adjusted to different moisture levels prior to storage. Acorns were soaked and then redried to the moisture contents shown, except for the control (40-42% moisture content) which was not soaked. Vertical bars are one standard error. Note:The germination test was six weeks long, which may not be sufficent time for all acorns to germinate.

Table 2. Effect of acorn pretreatment on emergence and seedling growth in Ballintemple Nursery in 2004.

Parameter	Standard	Soaked
Emergence (number/m^2)	113	147
Plant height >30 cm (number/m^2)	59	67
Plant height >40 cm (number/m^2)	34	40
Mean root dry weight (g)	6.86	7.31

Other pretreatments

The principal other approaches used (mainly in addition to prechilling) to improve germination potential include: priming or invigoration, freezing and IDS (incubation, drying, separation) methods.

<u>Priming</u>

Priming involves incubating seed in a warm (usually 15-20°C) environment for a short period before sowing (Downie and Bergsten 1991). It appears that priming stimulates metabolic activity which prepares seed for germination (Fujikura et al. 1993, Pill 1995). Primed seed can generally tolerate post-sowing environmental stresses better than non-primed seed (Schmidt 2000). Priming might be expected to result in higher germination and/or a faster rates of germination (Heydecker and Coolbear 1977, Coolbear et al. 1980, Bergsten 1993). Although seeds can be primed in the FI state, a lower (e.g. TMC) seed MC level will reduce the risk of premature germination and/or deterioration. Priming at either 15 or 20°C enhanced germination and speed of germination in the seed of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and noble fir (*Abies procera* Rehd.) (Doody and O'Reilly 2005), loblolly pine (*Pinus taeda* L.), and shortleaf pine (*Pinus echinata* Mill.) (Hallgren 1989). A short period (ca 2 days) of incubation at room temperature (ca 20°C) also slightly improved germination in alder and birch seeds (De Atrip 2005), but the method was most effective for the standard FI seeds (but there is a risk that the FI seeds will germinate prematurely if sowing is delayed).

<u>Freezing</u>

There are few reports on the possible beneficial effects of freezing temperatures on the germination response in tree seed. Freezing at -3°C for up to 12 weeks increased germination potential in alder and birch seed (Figure 5).

There was also evidence that oak acorns responded positively to freezing (Figure 4) (Özbingöl and O'Reilly 2005a). Suszka et al. (1996a) have reported that freezing improved germination in common alder, red oak (*Quercus rubra* L.) and Norway maple (*Acer platanoides* L.). Freezing might provide additional chilling, thus helping to release dormancy further, but the nature of the response to freezing may differ from that provided by conventional non-freezing chilling.

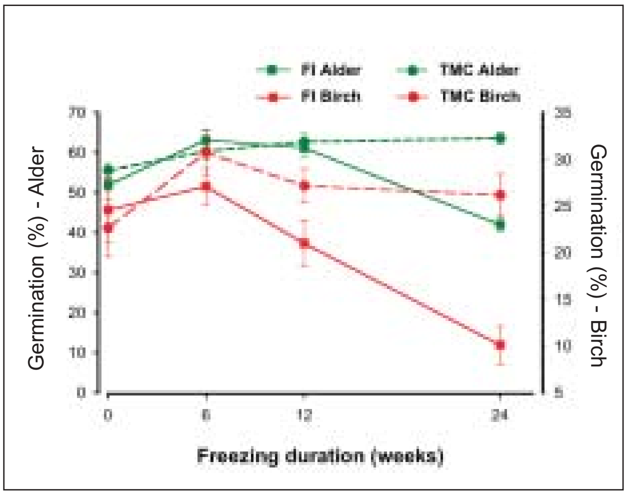

Figure 5. The effect of freezing (-3°C) duration on subsequent percentage germination at 15°C in alder and birch seed. Seed was prechilled in fully imbibed (FI) state or target moisture content (TMC) level before freezing. Vertical bars are one standard error.

<u>IDS treatment</u>

The incubation, drying, separation (IDS) method involves the use of a combination of priming and seed processing procedures (Downie et al. 1993, Downie 1999). Some steps can be skipped, depending on the characteristics of the species or seed lot. The method is particularly useful for separating non-viable from viable seed. Seed of some species (e.g. noble fir) contain a high proportion that are non-viable, but these may be difficult to separate if they are similar in size and weight. Using the IDS approach, separation is based on the principle that viable seeds lose water more quickly when dried after incubation than non-viable seeds, thus then allowing separation using conventional seed processing equipment (e.g. gravity tables). The period of incubation used may be short, when the method is used primarily to separate viable from non-viable seed. Longer periods of incubation can be used to invigorate low vigour lots. Furthermore, the last phase (separation) may not be used to treat a lot that is known to contain few non-viable seed. The IDS method is particularly useful where high seed viability is needed, such as in container nurseries and for precision sowing in a bare-root nursery. Most seeds are broadcast or drill sown in bare-root nurseries in Ireland, so there may be fewer advantages to using the IDS method.

POST-SOWING FACTORS

Many factors affect seed germination after sowing, but the most important are soil temperature and moisture availability. Although environmental factors (especially temperatures) cannot be controlled readily in a bare-root nursery, it is possible to take steps to minimise adverse effects. Since most bare-root nurseries in Ireland now have irrigation systems, soil moisture availability may be a less serious problem for germination now than in the past.

Soil temperature

The date of sowing has a large effect on its success, mainly due to the effect of soil temperature. Soil temperature is often too low or sub-optimal for germination, particularly for seed sown early in the season. For instance, if seed is sown too early in a cold spring, germination is likely to be slow, and although the seedlings may grow to an acceptable size by the end of the season, seedling yields may be low and variable. If seed is sown too late in a dry spring, germination may be lower than expected. Generally, seed should be sown as early as possible in spring after the soil temperature at the 10 cm depth exceeds 10°C (Thompson 1984), but this criterion may be less useful for seed of species that is sown at a shallow depth (e.g. grit covered). The temperature of the soil near the bed surface may provide the most useful information on the best time to sow small-seeded species that are sown at a shallow depth. The temperature at this depth may be 5-6°C higher than the daily maximum air temperature, while the lowest temperature may differ little from the minimum air temperature. Air temperature, therefore, is not a useful guide for the best time to sow. The optimum temperature for germination for each species should also be considered when deciding on the best time to sow.

Seed of most species will germinate better at warm than at cold temperatures. The level of dormancy present in the seeds (see above) may influence the response to seedbed temperature, which is likely also to vary with species and seed lot. This conclusion is supported by controlled laboratory tests conducted on Douglas fir and noble fir in Ireland (Doody and O'Reilly 2005). Douglas fir seeds germinated better at relatively high temperatures, whereas noble fir showed the opposite trend (Table 3). Germination also varied in alder and birch seed in response to temperature (De Atrip and O'Reilly, in prep). The optimum temperature for germination was 20°C in alder and 15°C in birch. Other species may show a similar response to germination temperature. Therefore, sowing operations should be scheduled to optimise the likely response to soil temperature.

There is evidence that seed pretreatment may reduce the sensitivity of seeds to temperature. In Douglas fir for example, seeds prechilled using the TMC method germinated well at both low and high germination temperature, whereas seeds given the standard FI treatment germinated poorly, especially at the low temperature (Table 4). Similarly, alder seeds that received the TMC pretreatment germinated well over a wide range of temperatures, whereas there was a clear optimal for those given the standard FI pretreatment (De Atrip and O'Reilly, in prep).

Seed coverings (including grit, sand, mulches and other materials) and cloches also potentially influence seedbed temperature. In Ireland, grit is the most commonly used material to cover conifer seed and small-seeded broadleaf species. The colour of the grit may influence germination: dark grits may become hot and damage seeds or newly germinating seedlings (Mason 1994). Other coverings, usually used in addition to grit, may influence temperature much more. Air temperatures up to 20°C above ambient have been recorded inside clear polythene cloches, but increases of 8-16°C are more usual (Thompson and Biggin 1980, Mason 1994). There is a risk that temperature may become too high inside a cloche, potentially inducing seed dormancy, but the risk is probably low for seed sown early in season. Plastic mulches might result in a similar response, although temperatures probably do not get as high under these coverings as under a cloche. However, these coverings also affect moisture availability, as discussed below.

Table 3. Effect of germination temperature on laboratory percentage germination of Douglas fir and noble fir seeds given the standard fully imbibed (FI) prechilling treatment.

Temperature	Douglas fir	Noble fir
20 (dark)/30 (light)°C	87.5	16.3
15°C constant	69.1	52.1

Table 4. Effect of standard fully imbibed (FI) versus TMC seed prechilling treatment on laboratory percentage germination at differernt temperature in Douglas fir.

Temperature	FI	TMC
20 (dark)/30 (light)°C	87.5	94.7
15°C constant	69.1	83.6

Moisture availability

Despite the use of irrigation in many nurseries in Ireland, low moisture availability is probably the most important post-sowing factor reducing germination of small-seeded species. Species with large seeds (e.g. oak, beech) may be less prone to desiccation damage, but they are still susceptible to it. Lack of sufficient moisture, even for a very short period, may greatly reduce germination. If dry conditions occur for a short period soon after sowing, the seed may dry back and become dormant, then germinate later when conditions are more favourable. Irrigation can be used to minimise the risk of drought damage, but it may be wise also to use other measures to help protect seed from damage (Mason 1994). Although late and uneven germination is a common symptom of drought effects, more severe drying may result in poor to no germination. Irrigation water may evaporate very quickly, especially during warm, dry, windy weather. Furthermore, the irrigation water may not be distributed evenly. Therefore, it may be difficult to keep the seedbeds moist enough to maximise seed germination.

Proper irrigation requires considerable skill to maintain appropriate moisture levels for germination. The type of nozzles used influence its efficacy. Those that deliver a very fine mist at frequent intervals are best. Nozzles used to irrigate growing plants, which normally generate large droplets are not suitable, as they may disturb and therefore damage small seeds. Furthermore, such irrigation may lead to overly wet conditions.

Although grit is effective in retaining moisture, it may be necessary to consider using other seedbed coverings. Sand, commonly used to cover seeds in nurseries in other countries (e.g. the US) (Tanaka 1984), may be more effective than grit in retaining soil moisture (De Atrip and O'Reilly 2006b), although it may not always do so (Gordon 1992a). However, the exact proportion of fine material (such as sand) in the grit may have a large effect on seed germination (Gordon 1992a, Lally and O'Reilly 1998). Sand is not suitable for use on its own in Irish nurseries because of a high risk that it will be blown away. Nevertheless, sand in combination with grit (2 mm covering of sand topped by 2 mm grit) resulted in better germination in alder in an experiment conducted at Ballintemple Nursery (Table 5). In addition to the judicious use of irrigation, this covering type might deliver better germination results than using grit alone for small-seeded species.

The depth of grit, gravel and sand used is also important. As a general rule, the depth of covering (including soil) should slightly exceed the length of the longest axis of the seed (Mason 1994), but unfortunately this is sometimes exceeded, resulting in poor germination.

Other seedbed coverings, such as cloches and mulches, can be used to improve the moisture regime for germination (they may also help to provide more favourable temperatures for germination, as mentioned above). For example, a fleece mulch is routinely used to cover birch-sown seedbeds in one Irish nursery, with generally favourable results. Most plastic mulches and some plastic cloches must maintain a seal to be effective. The sealed covering helps to retain moisture in the soil, so irrigation is not normally required. If the seal is not maintained, most of the moisture will evaporate. Rain or irrigation is not likely to penetrate these coverings effectively. Cloches are also prone to damage by wind, so maintaining a seal may be difficult to achieve under Irish conditions. Although perforated cloches can also be used, they may not maintain enough moisture in the soil. These coverings may greatly reduce the amount water that reaches the ground through rainfall and irrigation. Therefore if not used correctly, many of these coverings might also result in low germination.

Table 5. Effect of seed covering type on seedling emergence in alder in Ballintemple Nursery.

Standard grit (4 mm)	Sand (2mm) topped with grit (2 mm)
124	201

There is also evidence that exposure affects germination (especially in ash). Exposed seedbeds are likely to lose moisture more quickly than sheltered ones. It is also likely that a higher proportion of the resulting seedlings might die soon after germination, probably as a result of drought stress. (New germinants would have a shallow root system which might make them prone to drought stress.)

RECOMMENDATIONS

The following steps should be taken to maximise germination in the nursery:

Pre-sowing phase

- Use the optimal (preferably the TMC) method to prechill the seeds of most tree species.
- Plan sowing operations so that there is sufficient time to use the optimal treatment.
- Pretreated seeds are fragile so they must be handled carefully.
- Store pretreated seeds at -3°C until the time of sowing.
- Consider using other methods to improve germination (e.g. priming or freezing treatments).
- Soak oak acorns for 5 days before storing at -3°C until time of sowing.

Sowing and post-sowing phase

- Schedule sowing operations to suit the temperature requirement of each species/seed lot.
- Use seed coverings which minimise moisture losses.
- Make sure that the optimal depth of covering is used.
- Use frequent, light (mist) water applications (especially for small seeds) to irrigate seedbeds after sowing.

REFERENCES

Aldous, J.R. and Mason, W.L. 1994. *Forest Nursery Practice*. Forestry Commission Bulletin, 111. HMSO, London, England, 268 p.

Bergsten, U. 1993. *Removal of dead-filled seeds and invigoration of viable seeds: a review of a seed conditioning concept used on conifers in Sweden.* In: Edwards, D.G.W. (ed). Dormancy and Barriers to Germination. International Symposium IUFRO project group P2.04-00 (Seed problems); 1991. Forestry Canada, Pacific Forestry Centre, Victoria, British Columbia, pp. 7-15.

Bonner, F.T. 1987. *Seed biology.* In: Woody plant seed manual. http://www.nsl.fs.fed.us/wpsm/Chapter1.pdf, p. 47.

Coolbear, P,. Grierson, D. and Heydecker, W. 1980. Osmotic pre-sowing treatments and nucleic acid accumulation in tomato seeds (*Lycopersicon lycopersicum*). *Seed Science and Technology* 8, 289-303.

De Atrip, N. 2005. Effect of seed moisture content on dormancy and storage characteristics of alder and birch seeds. PhD Thesis, National University of Ireland, University College Dublin. 124 p.

De Atrip, N. and O'Reilly, C. 2005. Effect of moisture content and chilling duration on the germination of alder and birch seeds. *Seed Science and Technology* 33, 363-373.

De Atrip, N. and O'Reilly, C. 2006a. The response of prechilled alder and birch seeds to drying, freezing and storage. *Canadian Journal of Forest Research* 36: 749-760.

De Atrip, N. and O'Reilly, C. 2006b. Effect of seed covers and seed pretreatments on the germination response of *Alnus glutinosa* and *Betula pubescens* seeds. *European Journal of Forest Research* (published online September 2006).

Doody, P. and O'Reilly, C. 2005. Effect of moist prechilling and primimg treatments on the germination of Douglas fir and noble fir seeds. *Seed Science and Technology* 33, 63-76.

Downie, B. 1999. *Upgrading seed quality of conifer seed lots: the how and glimpses of the why.* In: Gertzen, D.E., van Steenis, E., Trotter, D., Kolotelo, D. and Summers, D. (eds). The Seedling Triangle, Proceedings 19th Annual Meeting Forest Nursery Association. Vancouver, British Columbia, pp. 6-19.

Downie, B. and Bergsten, U. 1991. An invigoration regime for *Pinus strobus* seeds. *Canadian Journal of Forest Research* 21, 1343-1348.

Downie, B., Bergsten, U., Wang, B.S.P. and Bewley, J.D. 1993. Conifer seed germination is faster after membrane tube invigoration than after prechilling or osmotic priming. *Seed Science Research* 3, 259-270.

Fujikura, Y,. Kraak, H.L., Basra, A.S. and Karssen, C.M. 1993. Hydropriming, a simple and inexpensive priming method. *Seed Science and Technology* 21, 639-642.

Gordon, A.G. 1992a. *Seed dormancy, seed treatment and seed sowing.* In: Gordon, A.G. (ed). Seed manual for forest trees. HMSO, British Forestry Commission, London, pp. 116-121.

Gordon, A.G. 1992b. *Seed storage*. In: Gordon, A.G. (ed). Seed manual for forest trees.HMSO, British Forestry Commission, London, pp. 98-104.

Gosling, P.G. 1989. The effect of drying *Quercus robur* acorns to different moisture contens, followed by storage, either with or without imbibition. *Forestry* 62, 41-50.

Hallgren, S.W. 1989. Effects of osmotic priming using aerated solutions of polyethylene glycol on germination of pine seeds. *Annals Forest Science* 46, 31-37.

Heydecker, W. and Coolbear, P. 1977. Seed treatments for improved performance-survey and attempted prognosis. *Seed Science and Technology* 5, 353-425.

Jensen, M. 1996. *Breaking of tree dormancy at controlled moisture content.* Combined proceedings international plant propagators's Society 46, 296-304.

Jensen, M. 1997. *Moisture content controls the effectiveness of dormancy breakage in* Abies nordmanniana *(Steven) Spach seeds.* In: Ellis, R.H., Murdoch, A.J. and Hong, T.D. (eds). Basic and applied aspects of seed biology. Kluwer Academic Publishers, Dordrecht, pp. 181-190.

Jinks, R.L. and Jones, S.K. 1996. The effect of seed pretreatment and sowing date on the nursery emergence of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) seedlings. *Forestry* 69, 335-345.

Lally, M. and O'Reilly, C. 1998. Effect of grit and grit source on the germination, early morphology and health of Sitka spruce (*Picea sitchensis* (Bong.) Carr.). *Irish Forestry* 55, 26-36.

Mason, W.L. 1994. Production of bare-root seedlings and transplants. In: Aldhous, J.R. and Mason, W.L. (eds). Forest Nursery Practice. HMSO, London, England, pp. 84-103.

Özbingöl, N. and O'Reilly, C. 2005. Increasing acorn moisture content followed by freezing-storage enhances germination in pedunculate oak. *Forestry* 78, 73-81.

Pill, W.G. 1995. Low water potential and presowing germination treatments to improve seed quality. InL Basra, A.S. (ed). Seed Quality - Basic

Mechanisms and Agricultural Implications. Food Products Press, New York, pp. 319-359.

Poulsen, K. 1992. *Seed storage physiology of recalcitrant acorns from pedunculate oak (*Quercus robur *L.) and orthodox nuts from the European beech (*Fagus sylvatica *L.)*. Ph.D. Thesis, The Royal Veterinary and Agricultural University, Copenhagen.

Poulsen, K.M. 1996. Prolonged cold, moist pretreatment of conifer seeds at controlled moisture content. *Seed Science and Technology* 24, 75-87.

Schmidt, L. 2000. *Guide to handling of tropical and subtropical forest seed*. Danida Forest Seed Centre, Humlebaek, Denmark.

Suszka, B. and Tylkowski, T. 1980. Storage of acorns of English oak (*Quercus robur* L.) over 1-5 winters. *Arboretum Kórnickie* 25, 199-229.

Suszka, B., Muller, C. and Bonnet-Masimbert, M. 1996a. *Seeds of forest broadleaves - from harvest to sowing*. INRA, Paris.

Suszka, B., Muller, C. and Bonnet-Masimbert, M. 1996b. *Seeds of forest broadleaves - from harvest to sowing*. Institut national de la recherche Agronomique (INRA), Paris, 295 p.

Tanaka, Y. 1984. Assuring seed quality for seedling production: cone collection and seed processing, testing, storage, and stratification. In: Duryea, M.L. amd Landis, T.D. (eds). *Forest Nursery Manual: Production of Bare-root Seedlings*. Martinus Nijhoff/Dr W. Junk, Boston, pp. 27-39.

Thompson, B.E. 1984. Establishing a vigorous nursery crop: bed preparation, seed sowing, and early seedling growth. In: Duryea, M.L. amd Landis, T.D. (eds). *Forest Nursery Manual: Production of Bare-root Seedlings.* Martinus Nijhoff/Dr W. Junk Publishers, The Hague/Boston/Lancaster, pp. 41-49.

Thompson, S. and Biggin, P. 1980. The use of clear polythene cloches to improve the growth of one-year-old lodgepole pine seedlings. *Forestry* 53, 51-63.

Weed and pest control in nursery production and their impact on plant quality

Heinrich Lösing

Woody plants can be attacked by many pathogens in the first, second and third growing seasons in the nursery. Different biological and chemical methods for control have been developed in the past to achieve the production of good quality plants to meet the demands of the customer.

WEED CONTROL

Mechanical and chemical weed control in nursery production have had a great impact on plant development and quality. Weeds and the nursery crop are in competition for nutrients, water and sunlight. To achieve good weed control from the beginning several mechanical weeders have been developed over recent years but their use in nurseries is limited to those situated on sandy, stone-free and free draining soils.

On seed beds, fumigation with Basamid Granulat (Dazomet) or other soil fumigants is still frequently used in nurseries. Steaming is an alternative to this practice but it is expensive and difficult to carry out in an open nursery.

A number of soil active herbicides are used for treating transplants, such as Afalon (Linuron), Butisan (Metazachlor), Galery (Isoxaben), Stomp (Pendimethalin) and Venzar (Lenacil). Other products with contact action such as DowShield (Clopyralid), Gramoxone (Paraquat) and Roundup (Glyphosate) are also used during the season.

Herbicide use is an important consideration in the nursery production cycle. Growers need to understand the action and selectivity of each product or combination of products. Damage to nursery crops by incorrect herbicide use is often incurred. It is highly recommended that growers start with a small scale pilot trial at first with any new product. Most herbicides cause specific symptoms on plants when damage occurs.

CONTROL OF FUNGI

Some fungi appear to have a kind of partnership with certain plant species, like powdery mildew (*Microsphaera alphitiodes*) on English oak or rust (*Melampsoridium betulinum*) on birch. They are always found on those plants and need to be managed carefully. Heavily infested plants show growth reduction and sometimes also dieback of the top branches in spring or in cold-storage.

Modern products used in farm production are very effective in controlling these fungi. For example, powdery mildew on oak can be controlled by spraying at 30-day intervals with

Figure 1: Metosulam + Flufenacet damage of oak.

Figure 2: Roundup damage of oak due to application as top dressing in late spring.

Figure 3: Powdery mildew on oak.

Picture 4: Woolly aphid on beech.

products like Fortress (Quinoxyfen) or Collis (Boscalid, Kresoxim-methyl), when treated before a high infestation of the crop occurs.

Other products, such as sulphur which have contact action applied during warm weather combined with the added effect of control of gall mites can be incorporated into the spraying regime.

Rust fungi on birch or alder (*Melampsoridium hiratsukanum*) can be treated very effectively with products like Folicur (Tebuconazole) or Bayfidan (Triadimenol). They may have a slight stunting effect on the crop, but often this is more of an advantage than a disadvantage, because plants tend to get too big in most years.

CONTROL OF INSECTS AND OTHERS

Different species of nematode can cause severe stunting in forest nursery crops such as cherry (*Prunus avium*) and beech (*Fagus sylvatica*) in fields which have been in nursery production for a long time. It is mainly *Pratylenchus* nematodes that cause the problem. Control is possible with fumigation or using products like Temik (Aldicarb). Biological control is also possible by growing *Tagetes* spp. for a growing season.

Some forest species like ash (*Fraxinus excelsior*) can suffer from gall mites (*Aculus epiphyllus*). The leaves turn brown on the underside and the plants show growth reduction. Most growers do not recognise the infection, because the gall mite is much smaller than the spider mite. Control is possible using any of the products that are used against spider mites.

Woolly aphids (*Phyllaphis fagi*) on beech seem to be the most difficult insect to control at the moment. The insects have increasingly developed resistance to products such as Admire (Imidacloprid). Alternatives (Clothianidin, Thimetoxam) are not yet available or belong to the same chemical group. Young plants of beech (*Fagus sylvatica*) often show extreme dieback after heavy infestation with woolly aphid.

Another example of dieback caused by insects is the gall midge (*Arnoldia quercus*) on oak, especially in the second and third growing season in the nursery when it causes dieback of the very young growth. Good control requires frequent application of Hallmark (lambda-Cyhalothrin) otherwise the plants will need to be hand-trimmed before shipment.

Figure 5: Gall midge damage on oak which has destroyed the leader.

SUMMARY

Pest and weed control are very important factors in achieving good plant quality in nursery production. Careful monitoring of both pathogens and weeds is necessary. Knowledge of biological and chemical control methods will give the grower the option of applying different methods of control to achieve the best results.

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Always start on a small scale with new products!

The role of tree improvement in plant production and quality

David Thompson

ABSTRACT

The four main objectives of this paper are:

1) to highlight the fact to the nurseryman and grower that there are certain inherent characteristics in each seed lot or clone that are controlled by genes which are foolhardy to ignore or attempt to over-ride by cultural treatments,
2) to show that traits vary genetically at the species, population (provenance), individual and even the clonal level,
3) to illustrate how tree improvement utilises this genetic variation to produce new improved individuals and varieties and
4) to explain how all this affects the work of the nurseryman.

INTRODUCTION

It is a basic tenant of biology that most major characteristics in living organisms are determined, at least in part, by genes inherited from their parents. By selecting parents with desirable traits and crossing them with others having different desired traits it is possible to produce a new combination of these desired traits in the offspring. This is the basis for genetic improvement in plants and animals that man has been doing for the last 8 to 10,000 years. Genetic improvement and specifically breeding of forest trees is a more recent development, starting in the 1920s, which really blossomed in the 1950s.

The question of how can you possibly expect to 'improve' on Mother Nature's handiwork with forest tree species in the lifetime of a tree breeder is a legitimate one. Nevertheless, Nature does not strive for optimisation or efficiency, she strives simply for survival. As a result the productivity of natural forests is only about $^1/_3$ to $^1/_5$ of the theoretical yield that forest tree species should be capable of producing (Table 1).

By selecting individuals with superior traits and crossing them with other individuals with different desired traits, some of the offspring will be as good or even better than the parents. In this way the gap between actual and theoretical productivity can be narrowed. It is also important to recognise the fact that while cultural practices such as fertilisation, respacing, draining and other such practices may improve productivity temporarily, genetic changes result in permanent changes in the individual and all the offspring that it will produce.

For breeding to be effective it is necessary to first have some degree of natural genetic variation in the trait of interest and secondly this variation needs to be indeed genetic and thus heritable. If there is no genetic variation, there is nothing to improve and if there is variation but if it is not passed on to the offspring, breeding will be of little effect.

Any breeding programme has one or a series of objectives that it is attempting to achieve. Initially most forest tree breeding programmes were mainly concerned about the 'adaptability' of the material they were producing. This means that the new material would survive and perform well under the new conditions where it is planted. Adaptive traits are those directly related to survival, growth development and reproduction. These include such factors as seed weight, germination and stratification requirements, phenology (timing of bud break and bud set), photoperiodic (day length) responses, survival, height and diameter growth, stem and crown form, flowering and seed

Table 1. Theoretical versus actual productivity of forests (Farnum et al. 1983).

Theoretical Mean Annual Yield	18 Mg/ha/year
Actual Mean Annual Yield	
Douglas fir natural forest	5.7 Mg/ha/year
Loblolly pine natural forest	3.6 Mg/ha/year

production, resistance to insects and disease and many others. However, most commercial tree improvement programmes are not interested only in material that is well adapted to local climatic conditions, but also in material that produces more wood, with an improved stem form, perhaps with good strength properties (mainly wood density) and perhaps with greater resistance to major diseases and insects. Thus breeding objectives have changed over time.

While genes control most traits in forest trees such as growth rate, stem form, wood properties, date of bud break and bud set, branching habit, stress tolerance and insect and disease susceptibility and/or tolerance, genes do not entirely determine the entire performance of the offspring. A basic genetic tenant is expressed as the equation **P = G X E** or **P**henotype = **G**enotype by **E**nvironment. This simply expresses the fact that when you look at an individual, be it a person, a race horse or a tree, you can only see the Phenotype which is the product of the Genetic information in that organism as expressed under the conditions of the Environment in which it is living. The same individual living under a different set of environmental conditions (more stressful or more optimal) might appear very different. So to look at the phenotype of an individual tells you very little about the genetic factors that make an individual they way it is. This problem will be discussed further in later sections.

SOURCES OF VARIATION

So where does all this genetic variation come from and how can it be utilised? Variations in most traits exist at almost all levels starting with the species, progressing to the provenances (material from geographic locations), on to families (offspring of selected individuals) and even to clones (vegetatively propagated selected individuals). In tree species, generally greater genetic variation can usually be found between individuals from the same population than can be found between different populations (provenances). Again, it is important that this variation is due mainly to genetic differences and not due only to environmental effects, hence the reason to test it in a range of different environments.

In order to achieve the largest amount of improvement it is essential to employ an improvement strategy that starts by selecting the species that provides the greatest likelihood of providing the improved material, followed by the use of the most suitable seed origin or provenance of that species, and finally the selection and testing of the individuals believed to have the traits of interest (‘plus trees’). To start by randomly selecting individuals (without regard to their origin) that look good and to clone them will not result in the greatest level of genetic improvement achievable, as selection at the species, provenance and family level has been ignored. It is necessary to progress logically from species to clone in order to capture the genetic variation at each step. Tree improvement also takes time, especially if it is to result in valuable improvements in the species of interest. There are no shortcuts in tree improvement.

Sources of variation at the species level

Different species vary greatly in their genetic characteristics. It is also important to consider non-native species, because most species are native only as a result of past climatic conditions or geographic situations and thus may not necessarily be the most suitable species for the conditions. Most exotic species do not suffer from local insects and diseases, which generally makes them more productive than native species. In many cases non-native species occupy an ecological niche not occupied by native species. Some species, by their very nature, are more adaptable to different conditions than others. For example, Monterey or radiata pine (*Pinus radiata*), although not an important commercial timber species in its native locations (California and islands off the Mexican coast) has become an economically important species in Australia, New Zealand, South Africa and Spain. Similarly, other species such as red pine (*Pinus resinosa*) while an important species in their native species range, has not proven to be as successful in other parts of the world.

Species from regions with rather uniform climatic conditions may provide only limited genetic variation in certain adaptive trials. For example, Sitka spruce (*Picea sitchensis*) which has a long narrow coastal natural species range provides a very limited range in the date of bud break (7 to 10 days between provenances) and this provides essentially no protection against late spring frost. Other spruce species, such as Norway spruce (*P. abies*), which ranges from high elevation to sea level, and covers a large north to south and east to west range, can provide large differences in the date of bud break (months), because of the wide range of climatic conditions where it is found.

These genetic differences between species are due to underlying physiological differences. In a comparison of Sitka spruce, Interior spruce (*Picea glauca* x *P. engelmannii*) and the hybrid between these two species, it was found that the coastal Sitka had a higher gas exchange rate (greater net photosynthesis and stomatal conductance) than Interior spruce, and the hybrid between the two was intermediate between the parents, as would be expected if these traits were indeed under genetic control (Fan et al. 1999).

Sources of variation at the population or provenance level

Once the species has been selected, perhaps one of the largest and most effective increases in productivity and quality can be achieved by selecting the most suitable seed origin or provenance for the local conditions. For native species the local provenance is not necessarily the best in terms of production and quality, asit is only the material that has consistently survived under local growing conditions in the relatively recent past.

At the provenance, or population level Burley (1965) reported that Sitka spruce provenances from Alaska and California showed little difference between the date of bud break (about two weeks) but showed about a one month difference in the date of bud scale formation. While this is important in the nursery, these factors are regulated by a combination of changing day length and temperature and cannot effectively be altered by cultural practices. In native northern European broadleaf species such as beech, oak and ash, it appears that eastern European origins break bud first while western European sources break bud later, thus providing some protection against late spring frosts which are common in western Europe.

Ludlow and Jarvis (1971) reported that the slower growing northern seed origins of Sitka spruce (Alaska) showed increased photosynthesis rates and a reduced dark respiration rate compared to faster growing southern origins (Washington). It is likely that in spite of the more efficient photosynthetic rates of the northern material it is the longer growing season that makes the southern material more productive.

Murphy and Pfeifer (1995) found that southern provenances of Sitka spruce had fewer and small diameter branches which would result in fewer and smaller knots thus improving the strength properties of the timber.

Sources of variation at the individual or family level

Because, for the most part, forest tree species have been left undomesticated, they exist as tremendous sources of variation. Therefore superior individuals or ‘plus trees’ can be selected from either native stands or plantations and serve as the basis of a tree improvement programme. Because these superior individuals are the result of a specific genetic by environment (G X E) interaction, as discussed earlier, it is necessary to compare them in a common test environment. This is done by growing their offspring or ‘progeny’ in a range of different environments, together with a control or standard seed source to determine if they are indeed superior across a range of site types where it will be grown. Testing takes time (typically $^1/_4$ to $^1/_3$ of the full species rotation length) to identify the superior individuals. It is also necessary to select only the top 10 to15% of all plus trees tested, in order to achieve the greatest level of genetic improvement. If selection intensities are not high enough, lower levels of improvement will result. This also means that a significant number of candidate plus trees must be selected and tested in order to have a large enough breeding population to support an improvement programme. Several hundred candidate plus trees are needed if even a small breeding population of 20 to 50 individuals is to be available.

Proven superior ‘plus trees’ either serve as parents in the production of improved ‘families’ (offspring) or can serve as superior individuals for clonal propagation.

At the family level Tan et al. (1995) showed that in black spruce (*Picea banksiana*) a difference in the allocation of photosynthate could be seen between different families grown under stress conditions. The more vigorous families tended to allocate photosynthate to needles, with the less vigorous families allocating more to the roots. Under optimal growing conditions these differences between families were not observed. This again highlights the importance of testing individuals under a range of environments.

Differences in drought tolerance were also seen between families of black spruce (Major and Johnson 1999), as well as differences in photosynthetic characteristics (Major and Johnson 2001). Marshall et al. (2001) found that the taller families of Ponderosa pine (*Pinus ponderosa*) were the first to begin photosynthesis in the spring, and maintained it longer into the autumn than shorter families. They also reported that taller families of western white pine (*Pinus monticola*) had higher rates of water use efficiency and lower photosynthetic rates than shorter families on warm, late summer days.

While as discussed above, there is very limited genetic variation in the date of bud break in Sitka spruce at the provenance level, it has been possible to identify individuals that may break bud 2 to 4 weeks later than average and yet still achieve above average annual height increments (Thompson, unpublished). Such individuals, if enough could be found, could serve as the basis for developing a late flushing variety for protection against late spring frost damage.

Sources of variation at the clonal level

As discussed in the preceding section there can be very large differences between individuals of the same provenance or even within individuals the same family. This individual variation can be best captured and utilised by clonal propagation where the resulting plants are exact genetic copies of the original. Cannell et al. (1983) reported differences in dry matter distribution between clones of Sitka spruce and lodgepole pine (*Pinus contorta*). Sparsely branched clones in both species were found to allocate the greatest proportion of their dry matter to the main stem. Sheppard and Cannell (1985) reported the identification of 'nutrient use efficient' clones of both Sitka and lodgepole which produced more biomass under conditions of reduced nutrient availability.

Coutts and Nicoll (1990) reported a difference in the mycorrhizal associations formed with different clones of Sitka spruce. Deans et al. (1992) found significant differences in the morphological quality and in the RGP (root growth potential) of different clones of Sitka spruce. Differences in the degree of frost hardiness between clones of Sitka were found by Nicoll et al. (1996) and differences in the susceptibility of Sitka clones to red deer damage was reported by Duncan et al. (2001).

The advantages of clonal material is that it reproduces exactly the genetic traits as the original individual (which might vary slightly under different environmental conditions). Clones will be much more uniform and predictable because of the reduced variation within the crop. Because vegetative propagation does not depend on flowering and seed production it can significantly reduce the time required to produce commercial amounts of improved material. Cloning depends on methods of vegetative propagation, as opposed to sexual propagation, and includes grafting, air-layering, rooting of cuttings and micropropagation (by both organogenesis or somatic embryogenesis). Typically, species vary in their ability to be vegetatively propagated and, in general, younger material is more responsive than older material. This causes problems because of the time needed to test individuals in order to identify the truly superior individuals, which by the time they have proven themselves it may no longer be possible to propagate them vegetatively.

It is also important to highlight the point that vegetative propagation provides no genetic improvement in the material it produces. Only by sexual propagation is there a recombining of selected traits from both parents to produce new individuals that combine the best of both parents. Thus, to be truly effective, material produced by vegetative propagation needs to have a breeding programme behind it to provide new and further improvements.

THE EFFECTIVENESS OF BREEDING

Plant breeding is based on the concept that by selecting good individuals and crossing them the resulting offspring will be as good or perhaps better than the parents. This is shown in the results of crossing different male and female parents in Sitka spruce as shown in Table 2.

It is important to note that in the Coillte Sitka spruce improvement programme only individuals that are 10% or more taller than the unimproved Washington control seed source will be considered as candidates for the breeding programme. As can be seen from the performance data of the different parents used in these crosses, none of these parents would have been selected for inclusion in the breeding programme. Nevertheless, when certain poor parents are crossed with other poor parents, in some cases even poorer offspring are produced (e.g. parent 125 crossed with parent 61). In other cases some very good offspring resulting from specific unique combinations of genes can result (e.g. parent 2 crossed with parent 140). It can also be seen that certain parents such as parent 56 and 140 produce some very productive offspring in a number of specific crosses.

LIMITS OF TREE IMPROVEMENT

Having said all this, tree improvement cannot provide the solution to all problems. It requires a significant period of time to select, test and then breed new material and as the old saying goes ‘time is money’. The level of improvement that is attainable is also important and varies with the species, so the question really becomes one of the ‘amount of gain achieved per unit time’. Obviously the greatest gain in the shortest amount of time is the ideal situation.

Typically, it is the fast growing conifers that have received the most attention, mainly because they are the major commercial species. The time required to test and accurately select superior individuals differs greatly between conifers and broadleaves, due to differences in the rotation lengths (recall the $^1/_4$ to $^1/_3$ of the rotation length required for testing). Conifers, with rotation lengths of 40 to 80 years require 20 to 30 years to produce improved material. In ‘shorter’ rotation length broadleaf species such as ash or sycamore 30 to 40 years would be required for a cycle of breeding. In the ‘longer’ rotation broadleaf species such as oak and beech probably 40 to 50 years or more would be required to produce improved material.

By its very nature improved material will always cost more than unimproved material. This is mainly due to the methods required to produce improved material, and not usually as a result of an attempt to recover some of the R&D costs incurred in developing it. Improved seed is typically produced in managed seed orchards, and costs more to produce than wild collected seed, but of course the improved material provides growth rate, stem form and wood property improvements not available in wild material. Controlled crosses between two specific individuals are more expensive yet. Vegetatively propagated material produced either by ‘macropropagation (rooted cuttings, grafting, air-layering) or ‘micropropagation’ (axillary of adventitious shoots formation, somatic embryogenesis) all require significant amounts of handling, which increases production costs. Propagation costs can eliminate certain technologies from commercial consideration because propagule costs must be kept as low as possible. However, the level of improvement possible with controlled crosses or vegetative propagation are greater than those provided by conventional seed orchards.

Table 2. Performance of controlled crosses in Sitka spruce (height as a percentage above the control seed lot).

	Male Parents	**2**	**56**	**125**
Female Parents		5.7	7.4	8.3
48	5.5	0.3	11.9	0.0
61	6.3	1.2	16.0	-1.4
140	5.5	21.4	18.4	7.4

Second row from top shows open-pollinated performance of male parents and second column from left shows open-pollinated performance of female parents.

Finally, the 'best' improved material will always be in short supply. Multiple propagation system (e.g. micropropagation to produce stock plants that provide cuttings for rooting) may be necessary to produce commercial amounts of improved material as quickly as possible (avoiding delays in flowering and seed production). The planting of mixtures of improved with unimproved material (which will be removed in thinnings to leave the improved material as the final crop trees) may also need to be considered to maximise the number of hectares planted with limited amounts of improved material.

WHERE IS THE FUTURE DIRECTION FOR TREE IMPROVEMENT?

For tree improvement to continue to provide the type of improvements required by the industry it needs to be in touch with the end users. The change in emphasis from adaptability, to increased production, to wood quality is evidence of this reaction to industrial needs. However, exactly what properties of wood are most important for the future is not clear. There also needs to be a good connection with forest managers and nurserymen who will manage and produce the improved material.

Perhaps more importantly, breeders currently select individuals which phenotypically have the traits they want, with little or no understanding of how these desired traits are produced. For example, increased growth can results from a number of reasons, including early bud break or late bud set, however, this may be at the expense of damage or loss due to late spring or early autumn frosts. Thus a better understanding of the physiological basis for improved traits could play a more critical role in a tree improvement programme in the future and might also help make the identification of superior individuals more efficient than phenotypic selection alone.

WHAT DOES ALL THIS MEAN TO THE NURSERYMAN?

The genetic variation between species, provenances, families and even clones has a large effect on their production in the nursery. Differences in the date of seed maturation, seed stratification requirements, germination rate and length of the growing season vary by species, provenance, family and clone. Differences in the date of bud break, date of bud set, length of the growing season, number of branches and other such morphological differences can easily be seen between different materials in the nursery bed. What may be less apparent, and perhaps more important, is the fact that there are underlying differences in the physiology of different species, provenances, families and clones as well.

This has implications for the production of plant material in the nursery. For example in Sitka spruce plants derived from more northerly sources, such as the Queen Charlotte Islands off the coast of British Columbia, tend to stop shoot elongation and set bud by late August or early September, become dormant by early to mid October, and are ready for lifting by early November. More southerly sources from Washington continue to grow into early October and set bud by early to mid November and become dormant in late November so they are ready for lifting by early to mid December, or about one month later than QCI plants. Thus, if the nurseryman lifts both QCI and Washington Sitka at the same time, even though it is the same species, there will be inherent differences in the hardiness and thus survival potential of the plants even though the may have come from adjacent beds in the nursery and were grown under the same cultural regime.

As a result it is important to understand these inherent genetic differences in different species, provenances, families and clones that cannot be manipulated by cultural practices. It is better to understand these differences and work with them rather than to try and work against them.

REFERENCES

Cannell, M.G.R., Sheppard, L.G., Ford, E.D. and Wilson, R.H.F. 1983. Clonal differences in dry matter distribution, wood specific gravity and foliage 'efficiency' in *Picea sitchensis* and *Pinus contorta. Silvae Genetica* 32(5-6):195-202.

Burley, J. 1965. Provenance variation in growth of seedling apices of Sitka spruce. *Forest Science* 12(2):170-5.

Coutts, M.P. and B.C. Nicoll. 1990. Growth and survival of shoots, roots and mycorrhizal mycelium in clonal Sitka spruce during the first growing season after planting. *Canadian Journal of Forest Research* 20:861-68.

Deans, J.D., Mason, W.L. and Harvey, F.J. 1992. Clonal differences in planting stock quality of Sitka spruce. *Forest Ecology and Management* 49:101-7.

Duncan, A.J., Hartkey, S.E., Thurlow, M., Young, S. and Staines, B.W. 2001. Clonal variation in monoterpene concentrations in Sitka spruce (*Picea sitchensis*) sapling and its effect on their susceptibility to browsing damage by red deer (*Cervus elaphus*). *Forest Ecology and Management* 148:259-69.

Fan, S., Grossnickle, S.C. and Sutton, B.C.S. 1999. Relationship between gas exchange and carbon isotope discrimination of Sitka x Interior spruce introgressive genotypes and ribosomal DNA markers. *Tree Physiology* 19:689-94.

Farnum, P., Timmis, R. and Kulp, J.L. 1983. Biotechnology of forest yield. *Science* 219 (4585):694-702.

Ludlow, M.M. and Jarvis, P.G. 1971. Photosynthesis in Sitka spruce (*Picea sitchensis* Bong.) Carr.). Journal of Applied Ecology 8: 925-53.

Major, J.E. and Johnson, K.H. 1996. Family variation in photosynthesis of 22-year-old black spruce: a test of two models of physiological response to water stress. *Canadian Journal of Forest Research* 26:1922-33.

Major, J.E. and Johnson, K.H. 2001. Shoot water relations of mature black spruce families displaying a genotype x environment interaction in growth rate. III. Diurnal patterns as influenced by vapour pressure deficit and internal water status. *Tree Physiology* 21:579-87.

Marshall, J.D., Rehfeldt, G.E. and Monserud, R.D. 2001. Family differences in height growth and photosynthetic traits in three conifers. *Tree Physiology* 21:727-34.

Murphy, P.G. and Pfeifer, A.R. 1991. *Wood density and branching characteristics of Sitka spruce provenances grown in Ireland.* In: Joint meeting of Western Forest Genetics Association and IUFRO Working Parties S 2002-05, 00, 12 and 14, Douglas fir, contorta pine, Sitka spruce and Abies breeding and genetic resources. Olympia, Washington.

Nicoll, D.C., Redfern, D.B. and McKay, H.M. 1996. Autumn frost damage: clonal variation in Sitka spruce. *Forest Ecology and Management* 80:107-12.

Sheppard, L.J. and Cannell, M.G.R. 1985. Nutrient use efficiency of clones of *Picea sitchensis* and *Pinus contorta*. *Silvae Genetica* 34(4-5):126-32.

Tan, W., Blake, T.J. and Boyle, T.J.B. 1995. Early selection for drought tolerance and relationship to dry weight partitioning in black spruce families. *Forest Science* 41(1);168-80.

Practical management for quality in nursery production

John Kavanagh

In the practical management for quality in a nursery, all staff must be aware of what the nursery is aiming to produce, i.e. quality plants. For this reason it is important that staff understand the definition of a 'quality plant'. Quality in this paper means the fitness of plants for planting in the forest. It should be remembered that good quality plants have a better chance of becoming established and getting away to a good start than poor quality plants. Attributes of quality plants which should be highlighted in nursery practice include:

a) An awareness of the importance of using the best and most suitable seed sources is essential. Knowledge of origins and provenances is useful, and the importance of keeping plant material of different sources separate should be emphasised.
b) Staff should be aware of the importance of the target height and sturdiness for planting stock. This is especially important in the grading process; poor, weak plants should be culled.
c) It should be explained to staff what to look for in a quality plant in terms of root:shoot ratio, especially when they are directly involved in the grading, undercutting and lifting operations. Other important physiological features to be aware of include target root collar diameter, which should be randomly checked during the grading process
d) Staff must also be aware of other important features such as minimum and maximum sizes acceptable to the customer as well as the general overall health of the plant and freedom from insect damage and disease.
e) It is important to be clear on what the customers requirements are and to make sure that these needs are being fulfilled.

It is important for nursery staff to understand what is meant by a 'quality plant' and how their work can affect this quality.

All nursery staff must be aware of the impact of their actions and the influence of their work on these characteristics, otherwise they could be causing an adverse effect on plant quality or even damaging the transplant without realising it.

When we think of quality control in a nursery, we tend to think of the process of grading and its effect on the final product. However, quality control should begin at a much earlier stage, at seed bed preparation and seed sowing: it must be in place at all stages of the operation. Quality control does not have to be a formal system, but there must be designated and trained staff members with responsibility in keys areas in order to monitor and record work at the various operations.

In the process of lifting, grading, packaging and dispatch of plants a lot of good work can be undone by poor plant handling. The nursery must have systems in place to monitor and avoid this.

Continuous training of staff, and monitoring their performance, must be an ongoing process. For example, quality control in the grading shed must be a continuous operation as well the monitoring of stock quality while lifting in the field and coming in to the shed. After the grading process is completed the handling and dispatch of plants from the nursery should be constantly monitored. While transportation from the nursery may be outside the control of the nursery management, attention to packing and handling is essential.

Attention to detail at every stage during the growing cycle determines the ultimate quality of the final product. This means paying attention to such questions as:

- What is the ideal target seedling density in the seed bed?
- What is the quality of the seed to be sown?
- What is the actual seedling density and does this alter the original plan?
- Do we grow a transplant or an undercut seedling, and what is the most desirable growing cycle - will it be a one, two or three year transplant?
- Are the plants produced to the satisfaction of the customer?
- How are the plants performing in the field – it may be useful to discuss these and related issues with the customers

EXTERNAL FACTORS

Many external factors affect plant quality and nursery management should have systems in place to mitigate these factors, which include weather conditions, soil conditions, weed control, pest and disease outbreak and its control.

For example, staff must be aware of the importance of when weather conditions are too dry – when you need to irrigate, when not to; or when it comes to seed sowing or lfting of transplants, when are soil conditions right for the operation – not too dry or too wet. Sometimes it is better to postpone these operations, than to rush in when soil conditions are poor and end up with a bad result.

Vigilance is required from key staff members when it comes to weed control, pest control and disease control. Management and staff must be aware of what to look out for. It is important that the nursery manager is notified of anything happening in the nursery that is out of the ordinary.

OPERATIONAL FACTORS

Staff and management should operate as a team, which involves key people in the operational sectors that affect plant quality, i.e. ground preparation, seed bed establishment, seed sowing, chemical and fertiliser application, undercutting, transplanting, lifting, grading, and plant handling and storage prior to dispatch.

▲ *The various operations involved in nursery production have an impact on the quality of plants produced.*

There must be continuous dialogue between the staff involved in these operations and also between the management and staff.

In the transplanting operation for example, staff involved must be made aware of the impact of their actions and how these actions will directly affect the crop that they will be lifting and grading the next year.

Staff operating machinery must be made aware of the importance of avoiding mechanical damage of plants during chemical and fertiliser applications and other mechanical operations.

With this in mind there is an onus on the manager to know the limitations, or more importantly, the strengths, of the work force, i.e. which people are best suited to specific jobs and staff should be selected accordingly.

UNDERPINNING QUALITY IN THE NURSERY

To underpin quality in the nursery, a manager must depend on key people. To achieve success their skills must be developed. It is necessary that they operate as a team and take ownership and responsibility for the quality of their own work and that of their colleagues.

Because of the nature of the nursery business, there must be a continuous emphasis on team building and team work, combined with ongoing staff training, for both full-time and casual staff.

It is also important that experienced members of staff are encouraged to continue to examine how things might be improved, from a quality or efficiency point or view. Examples of this would be modification of a machine or suggesting ways to streamline various aspects of plant handling and production. This can be achieved by informal experimentation, complemented by formal research.

Improvement of plant quality through nursery research and added value

Patrick Long

John Kavanagh has talked about the management of quality in terms of day-to-day nursery management. My talk is going to take a more holistic approach to plant quality from a business perspective. It is perhaps apt that I first state that, for a nursery business, quality is a double-edged sword because it costs money to provide it and it costs money if you don't!

I show an example of a hybrid larch crop for which, in standard sizes of 30 cm+ height, we achieved a minimum price of €215 per 1,000 (Figure 1). Grading to a robust root collar diameter of 5 mm provides a yield of 70%. However, grading to a minimum of 40 cm in height drops plant yield to less than 60% which, on current pricing levels (€235 per 1,000), results in a drop of 10% in potential revenues to the nursery. If the customer further demands a strong root collar diameter (minimum of 6 mm) then the nursery would need to get a 25% price premium to compensate for the potential loss in yields from grading to this specification.

Realistically, the price obtainable in the market place is the price that the nursery can charge to the customer. Nevertheless, nurseries need to be earning a sustained level of profit in order to invest in three years 'work-in-progress' of plant stocks to meet customers' requirements and to be able to carry the necessary nursery infrastructure to produce quality crops. The question is how can they do this in a very competitive environment. The answers, I believe, are:

- adding value in terms of both products and services, and
- investing in research and process improvement.

Coillte Nurseries seeks to add value to the products that it grows through several means. The obvious priority is to provide the type of plant that our customers (and we) feel will have the greatest chance of survival in an out-planting situation. Often this is a question of balancing the ideal with what is economically feasible. To do so requires a heavy emphasis on reviewing growing systems to provide what the customer wants at least cost to the nursery. Irish nurseries are well able to compete on conifer production but find it difficult to compete against imports of one-year old broadleaf stock from mainland Europe. The question is whether a one-year old broadleaf plant is sufficiently robust to be used on an afforestation site with the potential for heavy competition from weeds. I believe not – but many customers merely have a view for short term price gains.

Coillte Nurseries management of the National Seed Centre ensures that the Irish forest nursery industry has the best provenances of seed available for production of plants for Ireland. Imported plants may not always have the same 'pedigree'. In addition, Coillte Nurseries also adopts a strategy of promoting even better selections of plant material. For example, we place heavy emphasis on the production of southern provenances of Sitka

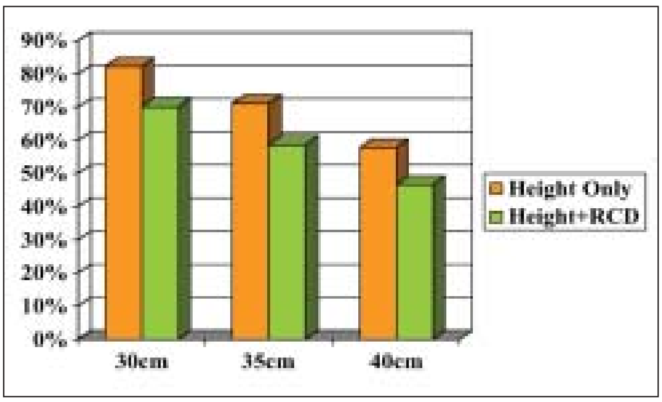


Figure 1: Hybrid larch yields based on height and RCD specification.

spruce over that of QCI due to the former's higher rate of productivity for the forest owner. We also invest in improved selections of Sitka spruce for our own company where increased productivity and better timber quality are a priority – even at the cost of more expensive planting stock.

Finally, we find it important to provide an option between both bare-root and containerised planting stock to provide our customers with opportunities for both mechanised planting and extension of the normal planting season.

Quality isn't all about plants – it's also about service. Irish forest nurseries have gone down the road of facilitating customers by providing delivery of plants straight to planting site, often at very short notice. In addition, significant risk is taken by providing cold-storage of plants to allow customers to extend their planting season. Recently, Coillte Nurseries has also invested heavily in the provision of chemical protection to planting stock against attack by pine weevil prior to the dispatch of plants to the site.

Cold-storage is a prime example of the customer demanding a 'product' that is not entirely suited to their circumstances. Figure 2 shows the general trend of plant sales for Coillte Nurseries in the spring season. A third of plants are dispatched to customers after 1 May when, it may be argued, planting should actually be winding down and maintenance programmes winding up. We always have customers with problems with plant survival from cold-store – particularly for less robust species like firs and larches – and they wonder why! Folks – nurseries don't particularly want to provide cold-storage. We don't make money from it – in fact year in, year out we lose money through operating costs and plant destruction.

Pre-planting treatment against pine weevil is an entirely different example. Working closely with our customers, we have managed to give a service that provides direct savings to the customer (even after paying a treatment charge). It provides better protection against weevil attack than field spraying, ensures that the chemical is applied in a controlled situation, reduces the amount of chemical used, and frees-up labour to continue planting during the period of greatest risk of weevil attack (March-April). Here's a service that reduces both environmental and health-and-safety risk and (most importantly) provides a good profit margin to our business!

Competitive advantage springs from the ability to grow and produce plants of a similar or better specification than your competitors, at a reduced cost. Plants are not the only objects that need to be cultivated in nurseries! We also need to cultivate an ethos of continuous improvement – what can we do better to meet the needs of the customer at a lower cost? Coillte Nurseries seeks to build this advantage through three main systems:

1. continuous review and development of both growing practices and business processes;
2. structured research programmes (both internal and in partnership with external bodies) to provide empirical evidence for changes to practices; and
3. availing of opportunities for technology transfer with others involved in our industry.

I would like to share a couple of examples with you on how research has helped to make us more effective and efficient in plant production.

The first is a study of the impact of grading hybrid larch seedlings prior to transplanting on final saleable yield and (ultimately) profitability

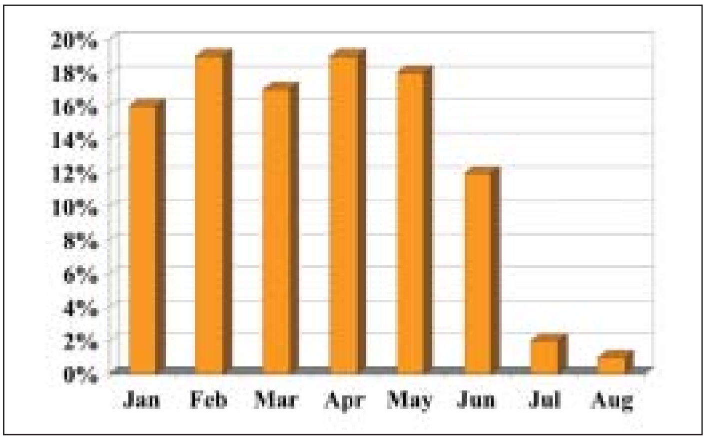


Figure 2: General trend of plant sales from cold-storage in the spring.

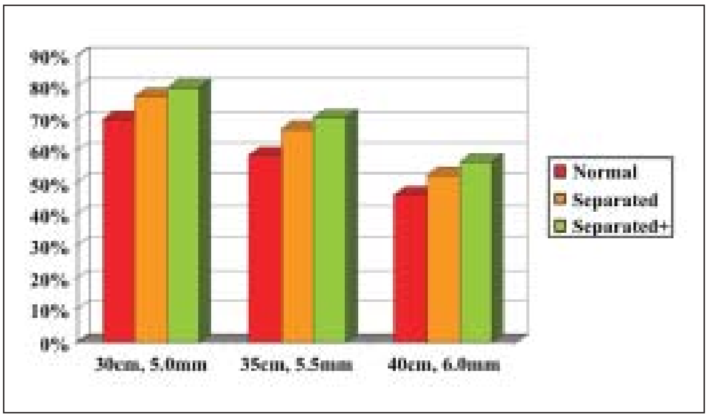


Figure 3: Grading of hybrid larch seedlings.

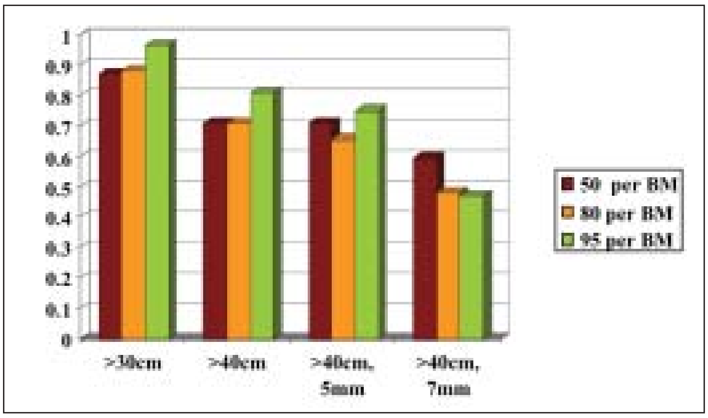


Figure 4: Sitka spruce transplant study.

(Figure 3). An initial assessment of the cost (€6.37 per 1,000 seedlings) would indicate that grading of seedlings prior to transplanting does not make sense. However, our study found that by discarding the smaller seedlings (less than 5 cm in height) and separating the balance into two grades (medium and large) resulted in a 20% increase in yields and, despite the increase in costs, up to 9% increase in net revenues. Here we had the opportunity to improve the quality of the product for our customers and to make a net contribution to our profitability.

The second study (Figure 4) looked at the effect of transplant density on the final height and root collar diameter of Sitka spruce transplants. In this study we were attempting to grow a plant that was consistently between 40 and 60 cm in height but had a root collar diameter of 7 mm+. We were convinced that we would have to reduce transplant density below our normal 90 plants per bed metre to achieve any material effect. Our study, in fact, showed that reducing transplant density had the opposite effect – reducing the yield of plants except for a height specification of 40 cm+ and root collar diameter of 7 mm+. At this point, the economic cost of increasing transplant area outweighed the benefits of improved yield.

In summary, I believe that Irish nurseries need to maintain their focus in order to survive in today's competitive environment. To achieve this they must seek competitive advantage through offering products and services of superior quality to that of their competitors. To achieve this in a cost effective manner requires an emphasis on product and process improvement through ongoing investment in research and development.

The effects of lifting and handling on plant quality: the Ontario perspective

Steve Colombo

INTRODUCTION

Ontario's has a land area of over 107 million ha, with about 66% or 70 million ha of that forested (Table 1). Most of Ontario's commercial forest is boreal forest, with the northern limit of commercial forestry at a latitude of about 51.5°N. Ireland, by comparison, lies entirely north of 51°N latitude, but due to its milder climate, the forests that can be grown there are dominated by warm temperate tree species. With a total area of about 8 million ha and a forest area of 660,000 ha, less than 10% of Ireland is forested. Although Ireland has only about 1% of the area of forests that Ontario does, the annual planting programme in Ireland is comparatively large, at about 20,000 ha compared to 75,000 ha in Ontario.

On average, over 200,000 ha is harvested annually in Ontario and forest fire affects from a few thousand hectares to over 300,000 ha every year (Figure 1). About 125,000,000 trees per year are planted, with all planting done using containerized conifers, mainly black spruce, jack pine, white spruce, red pine. The remaining harvested and burned areas are left to reforest by natural regeneration.

The high cost of planting means that the success of each plantation is important. The survival and good growth of plantations is also important to maintain wood supply to support a healthy forest industry. Controlling stresses affecting tree seedlings during handling, storage and shipping is crucial to successful regeneration of the areas planted.

STRESSES AFFECTING NURSERY STOCK

Many foresters and forest landowners do not realize how demanding the job of producing high quality seedlings in a tree nursery can be. There are a large number of growth events (e.g. bud burst, shoot elongation, root growth, etc.) that happen during the growing season (Figure 2). These growth events are affected by environment, which alters the rates and timing of each activity. In addition, insects and disease are potential problems which are usually not seen until they are about to become problematic. So the job of a nursery manager, who often has to deal with a number of crops of different species, ages, and provenances, is highly complex. After nursery managers produce a crop of high quality seedlings, the crop then goes under threat from stresses as the trees are lifted, packaged, shipped, and planted that can threaten to reduce its quality.

There is a long list of potential stresses that seedlings can be exposed to during handling; they include temperature stress (either too hot or too cold), water stress from desiccation, or mechanical stress from crushing or tearing. In addition, damaging concentrations of ethanol gas can accumulate if seedlings are sealed in airtight bags at warm temperatures, a situation that can also lead to the spread of the damaging storage mould *Botrytis*.

The risk of particular stresses affecting seedlings varies with stage of handling of nursery stock (Figure 3). Mechanical stress risk

Table 1. Selected statistics for the Republic of Ireland and Ontario, Canada.

	Republic of Ireland	Ontario
Population (millions)	4	12
Total area (millions of hectares)	8.4	107.6
Forested area (millions of hectares)	0.7	70.5
Proportion of area that is forest (% of total)	10	65
Area planted (hectares per year)	20,000	75,000

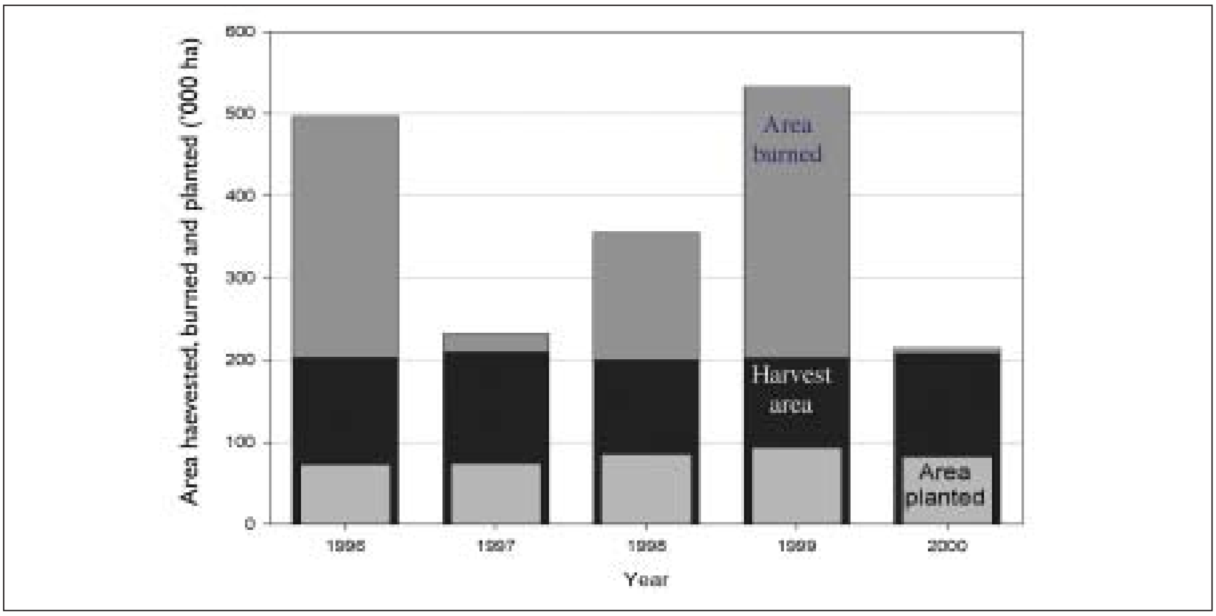


Figure 1. Forest disturbance and planting statistics for Ontario, Canada.

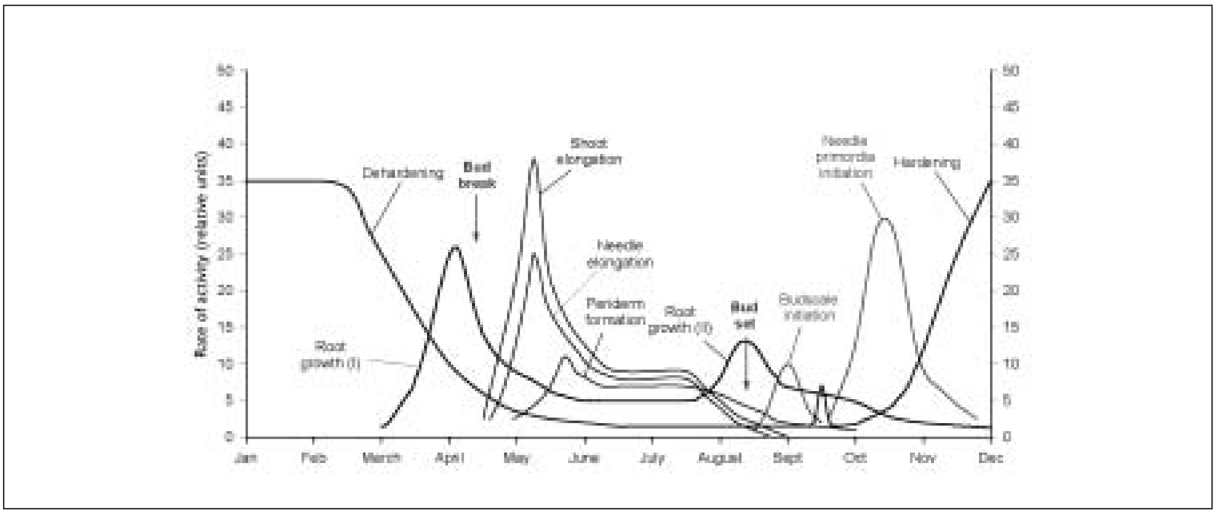


Figure 2. A typical annual sequence of growth rate and physiological condition that occurs to seedlings in a nursery. The rate or intensity of growth or physiological condition is shown by the height of the line on the y-axis.

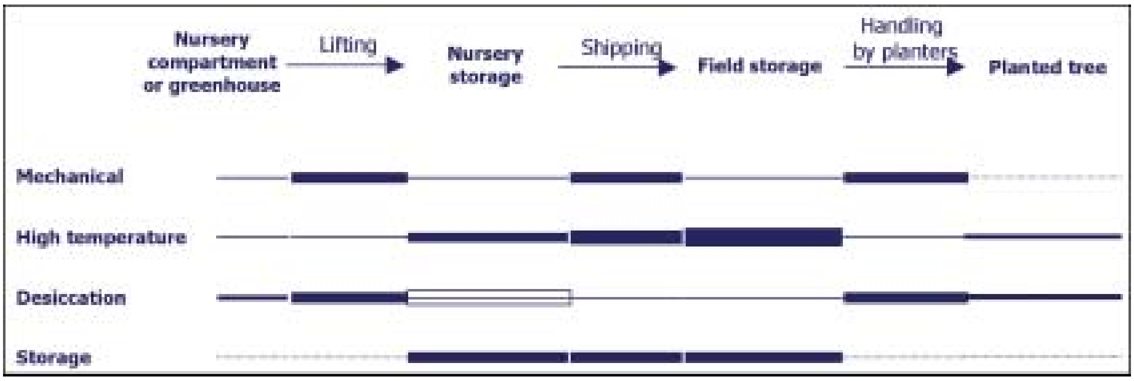


Figure 3. Risk diagram of handling stresses affecting tree seedlings. Thicker lines mean greater risk of damage from a stress during the time indicated.

is high when seedlings are being moved. Risk of high temperature exposure occurs when trees are packaged, with less sophisticated storage conditions and higher risk usually occurring in the field. The risk of desiccation is low after seedlings are packaged, but is particularly high during lifting or planting. Storage mould is a problem that is exacerbated by warm, moist conditions that can occur during storage in sealed shipping containers or bags (Figure 3).

A seedling's stage of seasonal development plays a major role in the susceptibility to stress. Ideally lifting, handling, shipping and planting are done when seedlings still have relatively high stress resistance. A generally good approach for maximizing the chance of success is to lift and store seedlings in the fall or spring when dormant, and ship them so they are planted as the soil warms. While it is common sense that an actively growing tree is less hardy than one that is not, there can be a substantial loss of stress resistance leading up to the time of budbreak when dormancy is being lost but before shoot growth is visible (Figures 4 and 5). Fall lifting for overwinter storage or planting should begin after hardiness increase (Figure 4). Lifting earlier can lead to damage in extended cold or frozen storage. Winter planted trees may produce some root growth after planting, but otherwise are inactive. Root and shoot growth resume in the spring when soil temperatures warm sufficiently.

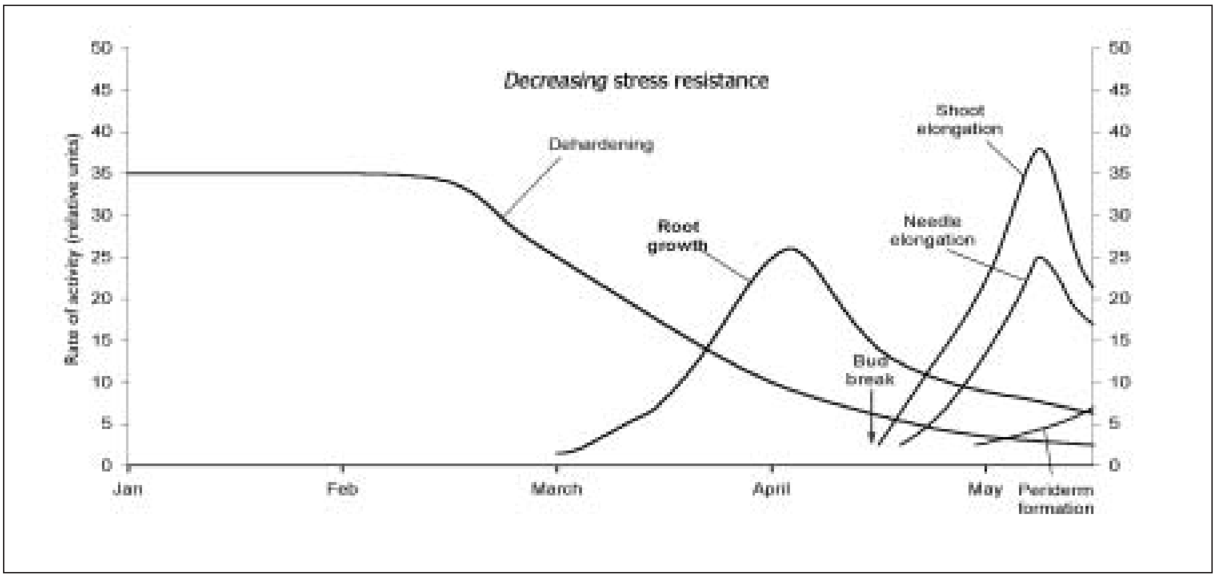


Figure 4. Spring sequence of growth rate and physiological condition that occurs to seedlings in a nursery.

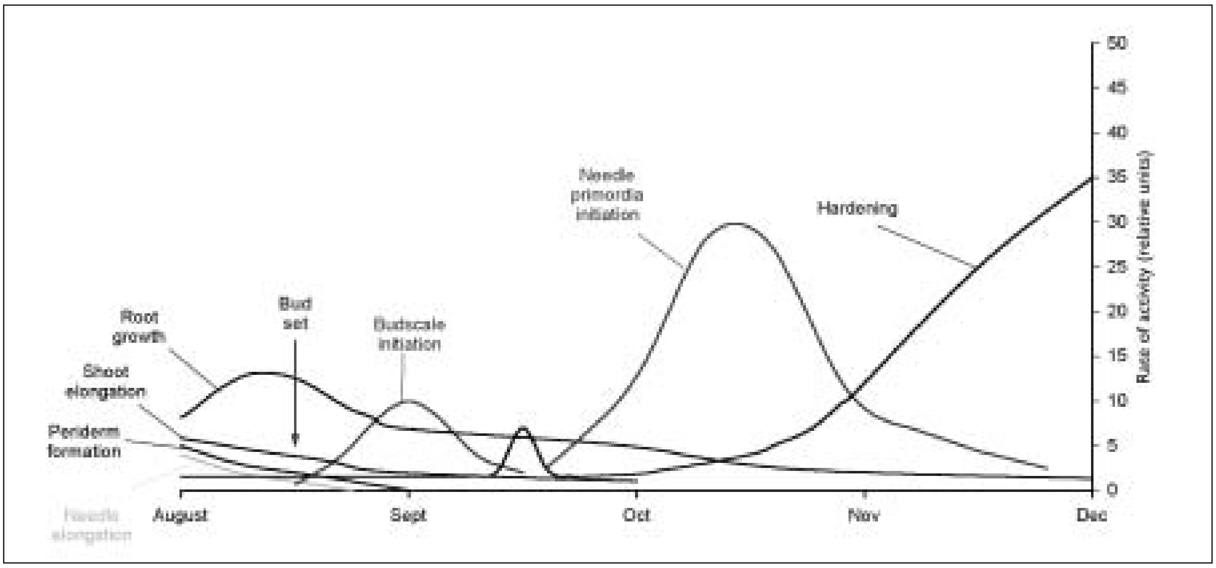


Figure 5. Fall sequence of growth rate and physiological condition that occurs to seedlings in a nursery.

Root damage can occur from mechanical undercutting (root tearing and desiccation) and hand lifting, particularly if intertwined roots are separated by pulling trees apart. During lifting, root desiccation can occur when fine roots are exposed to air. During sorting and grading of lifted stock, damage can occur if too much of the root system is removed (reducing water and nutrient absorbing surface area as well as reducing root growth after planting), although planting quality may be improved if excessively long roots are removed by trimming. To avoid excessive root trimming, trimming should be done on a small number of seedlings at a time.

Seedlings are moved from nurseries to planting sites in some form of shipping container, usually in bags. However, bags lend themselves to mishandling much more than boxes. Bags should not be tossed and they should be stacked in pallets so that there is air movement around them. High temperatures can reduce post-planting root growth, reduce ability to photosynthesize, and in severe cases can lead to bud, needle, and root tissue death. The period of exposure and the exposure temperature is crucial in determining damage, with the time to damage decreasing quickly with increasing temperature.

Table 2 summarizes many of the stresses affecting seedlings during handling and ways to reduce stress exposure. Many stresses can be reduced by fairly simple measures and often can be eliminated by communication and education on proper stock handling. In Ontario annual workshops have been conducted for tree plant contractors to remind them of the importance of plant quality and the vulnerability to stress. However, regardless of the measures taken, plants are going to be exposed to stress during handling and a means to identify stressed seedlings will reduce costly plantation failures.

TREE SEEDLING QUALITY ASSESSMENT IN ONTARIO

Avoiding seedling stress and detecting when it has degraded plant quality is helped by having available a standardized approach to quality assessment of trees prior to shipping from the nursery. Ontario has a long history of seedling quality testing. Frost hardiness testing was implemented operationally in 1982 to give nurseries information on readiness for lifting for winter storage. In the early 1990s, a Seedling Quality Assessment (SQA) programme was created to test nursery stock condition in the time between lifting and shipping, to improve plantation performance. Tests of nursery stock are conducted on a fee-for-service basis for forest companies and tree nurseries. Since 1993,

Table 2. Stock handling stresses that may affect seedling quality.

Time of Stress	Stress	Remedies
During lifting	Desiccation during lifting	Don’t loosen beds too far in advance of lifting crews
	Root tearing and loss during lifting	Precision sowing, row or box root pruning, and root wrenching
	Heavy root pruning after lifting	Precision sowing, lateral root pruning and root wrenching
During winter storage	Long-term cold and dark causing drying or respiratory loss Storage mould	• Lift when cold hardiness is high and store at subfreezing temperatures - minimize time of above-freezing storage • Minimize time in above freezing storage
During transport and planting site storage	Overheating Low oxygen levels in bags or boxes Storage mould	• Refrigerated field storage • Store trees under reflective tarps or under tree canopies • Open bags or boxes upon field delivery • Shorten time in field storage (small shipments planted quickly)
	Desiccation at planting site	• Ensure access to water at field storage sites for container stock • Planters carry fewer seedlings

over 2000 nursery stocklots in Ontario have been tested prior to their being planted. Testing is done by an independent, third party to provide an impartial judgment of stock condition. Testing is done in a controlled environment, so that daylight and temperature are constant from week-to-week and year-to-year, so the results are comparable from one time to the next.

WHY TEST SEEDLINGS?

The reasons for testing differ depending on whether you are the nursery producing the stock or the client whose land is being planted (Table 3). Both parties have an interest in producing vigorous plantations with high survival. Nurseries can use the results of stock testing as an aid in altering cultural regimes. Nurseries also can point to the results of favorable stock testing if damage or mortality appears after planting. This information can also help identify problems in stock handling. For clients whose land is being planted, nursery stock testing provides an assurance that the stock they have purchased is of prime quality and, given favorable handling and site environment, should produce a plantation with good survival and growth.

FROST HARDINESS TESTING

Shoot frost hardiness testing has been conducted operationally in Ontario for almost 25 years. The testing protocol was developed by forest researchers in the early 1980s and, due to the large number of nurseries and demand for testing, nurseries were encouraged to obtain equipment, and nursery staff were trained to carry out testing. A close relationship was built between researchers and nursery staff, with scientific support continuing to the present.

Frost hardiness of shoots is tested to aid frozen overwinter storage operations (the goal being to lift stock as soon as possible, but not before it is ready). In Ontario, shoot frost hardiness testing of most crops begins in late September. Seedlings are ready for storage when shoot frost hardiness reaches -40°C and cold soil temperatures have reduced root growth, usually by early November. Stock stored before becoming hardy usually shows up as damaged or low vigour when evaluated in the spring.

The method used in Ontario utilizes shoot tips cut from seedlings, which are frozen at a controlled rate in a programmable freezer, then thawed slowly, after which they are immersed in water. Electrical conductivity of the leachate is measured; if it is high damage is indicated and the shoots are not frost hardy. Low electrical conductivity means the trees are ready for frozen storage. The use of -40°C as the test temperatures might seem extreme, since seedling frozen storage is at -2°C to -3°C. However, when tissues freeze, ice forms in the relatively pure water in intercellular spaces of the needles and shoots. These points of ice formation slowly draw water from the non-frozen water inside cells (water in cells has a lower freezing point due to the high concentration of ions they contain). Frozen storage at even mildly freezing temperatures creates a long, slow but fairly extreme dehydrating stress on shoot tissues. Testing at -40°C recreates this stress in a short time span.

Table 3. Reasons to test nursery stock quality.

Testing party	Reason to have testing conducted
Clients	Planting decisions can be based on an independent assessment of seedling quality
	Evaluates seedling viability quickly when questionable stock reaches the field
	Identifies nurseries with consistently high quality stock
Nurseries	An aid for planning operations (e.g. lifting for cold or frozen storage)
	Prevents low vigour or damaged stock being shipped
	Establishes physiological baselines for improving the product and modifying cultural practices
	Improves a nursery’s competitive position for future sales

THE SEEDLING QUALITY ASSESSMENT PROGRAMME

Ontario's provincial programme of seedling quality assessment is available to tree nurseries, tree planters, and land owners. The programme provides a timely, third-party evaluation of stock viability, to identify damaged and physiologically impaired stock and prevent its being shipped or to allow some remedial action. Over the more than a decade it has been in existence, the programme has identified many nursery stock lots with damage. Decisions on what to do with damaged stock vary depending on the type of damage and the objectives of the landowner. In some cases, higher planting densities are used or the stock is sent for planting on a less stressful planting site. In a few instances, testing has detected problems that were severe enough to warrant a decision not to plant at all, although such cases are rare. Three types of tests are done: a visual examination, chlorophyll fluorescence of the foliage, and root growth potential.

Visual examination

In the visual examination a sample from a crop is tested for any signs of damage. Tissues examined are the foliage, cambium, terminal bud, coarse roots, and fine roots. The examination includes an external evaluation of damage to foliage while the cambium, buds, and roots are examined using a low power microscope after dissection. Samples are rated based on the percent of the tissue damaged and ratings are done in a consistent and repeatable fashion. Standardization of this basic assessment is important, since individuals might evaluate damage in different ways and so either miss something important or report it in a way that is hard to interpret.

Chlorophyll fluorescence

This test is simple to use, employs expensive equipment, and gives a rapid, numerical measure of the ability of the foliage to carry on photosynthesis. The basis of the test is as follows. Plants use light energy to convert carbon dioxide and water into sugar. Chlorophyll absorbs light and uses most of this energy in photosynthesis. A small portion of the absorbed light is re-emitted from the foliage as fluorescence. Light that is re-emitted is measured using the fluorometer. We use a fluorometer produced by the Walz company (Effeltrich, Germany). On leafless shoots it is possible to measure chlorophyll fluorescence of stem tissues.

Evaluations are made of the foliage at the top and mid-point of the stem after 2 and 7 days in the controlled environment of a growth chamber. Values greater than or equal to 0.7 are typical for healthy foliage. Values below 0.6 can indicate the presence of damaged foliage. When visibly unhealthy foliage is present readings are taken on non-symptomatic foliage to determine its condition. While the science behind fluorescence is complex, use of the equipment is fairly easy. In practice, an experienced person can often spot foliage that is unhealthy but still green — however, the advantage of using the fluorometer for this evaluation is that the machine puts a number on what the observer can see.

Root growth potential

Root growth potential (RGP) testing was introduced as a method of nursery stock evaluation more than 50 years ago and remains one of the cornerstone tests of tree seedling viability and quality. Its value comes from the fact that it integrates many key aspects of seedling functionality that are important to field performance:

- healthy root tissues with large numbers of root tips give high test values;
- root growth in conifers is fueled mainly by current photosynthesis rather from food reserves, so high RGP indicates high photosynthetic ability and healthy shoots;
- photosynthesis requires a healthy water transport system from the roots to the foliage; so high RGP also indicates that water absorption and translocation systems are unimpaired.

RGP testing is conducted by potting (or by hanging trees with roots suspended in a mist chamber). Roots are allowed to grow in a growth chamber at a controlled temperature, light intensity and daylength. After a standardized period of time the number of white roots 1 cm or more in length are counted. The time in the growth chamber needs to be just long enough to allow highly vigorous and non-vigorous stock to be differentiated: Timing is important because we use a qualifying length and count the number of roots reaching this 1 cm threshold. If left too long, stock of marginal quality can catch up and produce a large number of new roots 1 cm long. If not left long enough in the test the more vigorous stock will not express its superiority. If a continuous measure such as new root dry weight were used, timing would be less critical to differentiate quality among stocklots.

The results of RGP testing are rated against long-term average performance by species. Testing RGP in a controlled environment allows comparability of results with tests done at other times. We do not conduct RGP testing in a greenhouse since the results are affected by light levels and temperature. The large RGP database we have accumulated means that nurseries and foresters know how their seedlings compare. The RGP test period we use (7 days for container stock, 14 days for bare-root stock) is long enough that it allows damage to the trees to become evident. This is important as most stock in Ontario is stored and will not express latent damage until after planting.

As shown in Figures 6-8, good correlations have repeatedly been demonstrated between average RGP of a stocklot and its field survival. Although some researchers have failed to find such correlations, this is usually the result of not using a sufficient range of stock condition (e.g. if all the stock compared has high RGP then there is not spread in values to distinguish performance), or of planting sites that are harsh

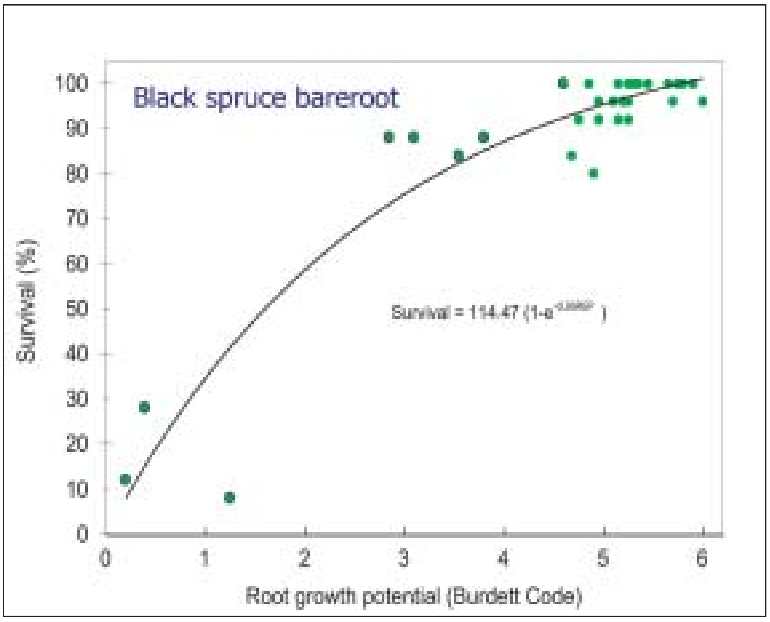


Figure 6. Relationship between plantation survival and root growth potential of bare-root black spruce. The Burdett Code of root growth potential is: 0 = no new roots, 1 = some new roots, none 1 cm in length, and Code values 2, 3, 4, 5, and 6 are respectively 1-3 new roots 1 cm or more in length, 4-10 new roots, 11-30 new roots, 31-100, or more than 100 new roots 1 cm or more in length.

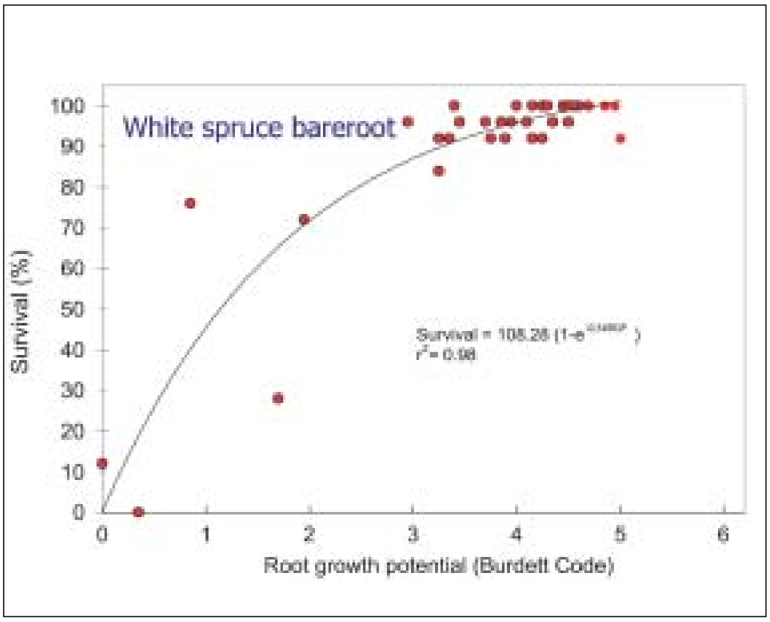


Figure 7. Relationship between plantation survival and root growth potential of bare-root white spruce.

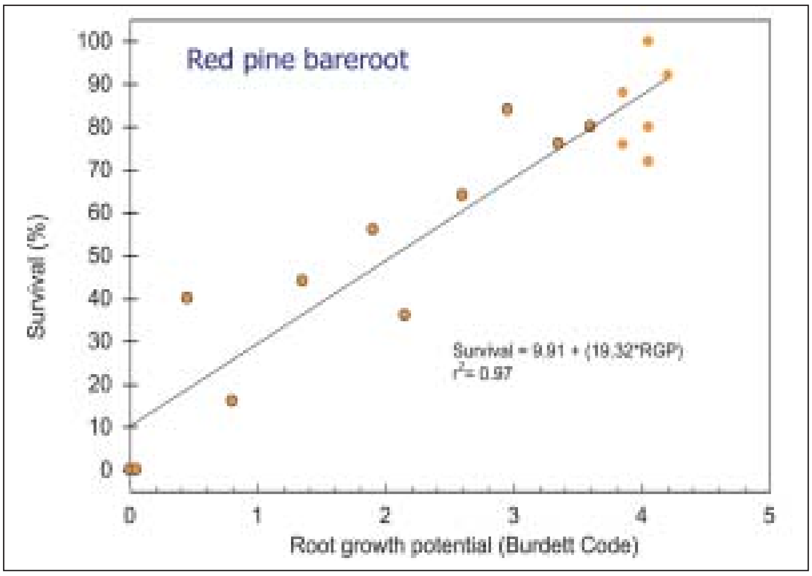


Figure 8. Relationship between plantation survival and root growth potential of bare-root red pine.

(under harsh planting site conditions the expression of differences in stock quality are suppressed).

The next steps that could be taken in Ontario's SQA programme are: To understand how to use nursery practices to get higher RGP (or how to avoid lower RGP); and To pay a premium for higher quality stock. Taking these steps will require co-operation among researchers, landowners, and tree nurseries.

EXTRAPOLATING STOCK TESTING TO IRISH FORESTRY

Knowledge of stock condition at the time of planting allows concerned parties to know when a plantation has problems due to planting site environmental conditions beyond one's control, or due to problems in quality related to nursery or handling problems. Without such information it is difficult to apply the principle of 'continual improvement', since relationships between nursery cultural practices, handling, stock quality, and field performance are difficult to unravel.

Independent stock testing increases confidence of nurseries (about stock handling) and their clients (concerning the quality of the stock they have planted) and would reduce the 'blame game' when plantation establishment problems inevitably arise.

RGP may be a useful test for Irish planting stock that is cold or frozen stored, where there is enough lead time between lifting and planting. The seasonality of RGP means that testing in late fall/early winter will give very low results; in such cases approaches such as root electrolyte leakage would prove more useful. Commercial forestry species such as Sitka spruce have been the subject of stock quality assessment in Great Britain and Pacific Northwest of North America, so a reasonably good knowledge already exists concerning test performance of species used in Ireland.

Using controlled environments to evaluate budbreak, root growth, damage, etc. would develop seasonal performance standards for Irish nursery stock (i.e. what is the 'normal' behaviour of stock grown in Irish nurseries). This information will let parties with an interest in reforestation know when nursery stock is performing better, worse, or differently than the norm.

CONCLUSIONS

Years of attention to growing quality stock can be lost very quickly through inattention to proper handling. Even a few minutes of mishandling can affect trees for several decades as they grow in a plantation.

Stock performance in standardized tests gives an objective measure that nurseries can use to show improvement in their products. A third-party testing programme gives all parties an independent assurance of the quality of the job they've carried out (during the nursery phase, during handling, and during planting).

By avoiding situations that stress trees during stock handling, clients who use nursery stock are provided with seedlings that have all the benefits and growth potential that were established during nursery production. This in turn helps produce plantations with high productivity.

Integrating establishment practice and plant quality

Mike P. Perks, Alan J. Harrison and Stephen J. Bathgate

ABSTRACT

The matching of species to site is of fundamental silvicultural importance. Considerations include information on previous land-use/crop, soil type(s) and climatic factors. Furthermore, at establishment a suite of silvicultural options may be considered including cultivation methods, fertilisation regime, time of planting and weed and pest control issues. In addition there is the influence of plant quality (age, size, method of production, storage) which can further influence early survival and growth of outplanted stock.

We describe the development of an Establishment Management Information System [EMIS] decision support tool that integrates existing silvicultural advice for tree establishment in upland forest restocking in Britain, on a site-specific basis. It draws upon information from many technical and scientific publications to provide the user with acceptable (site constrained) tree establishment options for restock sites. Site information (user input) allows calculation of environmental variables which constrain species choice, via integration with the Ecological Site Classification (ESC) decision support system and identifies appropriate on-site management practices. System development is guided by operational requirement and existing knowledge. EMIS output will be available as both HTML and pdf delivered via the web, however, the constituent models are also available as document-wrapped style web services to allow integration with spatial data (GIS) systems. This will enable delivery of spatially explicit good practice guidance in the future. Currently within Ireland the opportunity exists to develop similar systems based on the National Forest Inventory and other government agency datasets, existing technical publications and expert knowledge to ensure appropriate species-site matching and good silvicultural practice is adopted.

INTRODUCTION

National forest policies have expanded recently to include 'sustainable forest management' as an objective (Lane and McDonald 2002). Silviculture should ensure that any activity in the forest assists the achievement of the objectives defined by the manager (Smith 1986, Mason 1997). The first step in delivering sustainable forest management is the correct application of silvicultural knowledge at establishment, upon which all other decisions depend (Ray and Broome 2003). Such considerations, applied to a restock setting, include forest soil type (e.g. use of appropriate cultivation), operational impacts (e.g. minimising chemical use according to site specific needs) and timber production (e.g. identifying productive species well-suited to the site). In particular forest design planning has a wide range of 'competing' goals that the forester has to appreciate and account for (Bell 1998): where interaction between ecological (and social) components exists decision support system (DSS[1]) tools are useful (Rauscher et al. 2000). A key feature of DSS tools is that the decision-maker is an important part of a DSS, providing critical judgement and values that often dominate the decision-making process.

Whether reforestation or afforestation is involved successful tree establishment on upland sites requires knowledge of site constraints. These constraints include the general site environment (e.g. soil type, lithology, soil moisture and soil nutrient status), an understanding of the local climatic environment (e.g. wind climate, oceanicity, elevation, temperature profile), and the

[1] *DSS tools are computer-delivered programs that provide support to the decision makers engaged in solving various semi- to ill-structured problems involving multiple attributes, objectives and goals (Turban and Aronson 2000).*

interactions between these factors. The ability of the forester to assess site conditions and select well-suited tree species is therefore of fundamental importance, as is an understanding of the silvicultural options available to improve tree establishment and growth (Tabbush 1988). Silvicultural options include plant species and provenance choice (Morgan 1999), plant type, plant quality, plant storage and time and method of planting (e.g. Morgan 1999, McKay 1997), site cultivation (Sutton 1993, Paterson and Mason 1999), fertilisation (Taylor 1990a,b; Smith and McKay 2002) and vegetation management (e.g. Willoughby and Dewar 1995, Willoughby et al. 2004).

We describe a prototype expert system (EMIS), developed for establishment of forests in upland Britain to help with compliance to sustainable forestry guidelines. EMIS attempts to present the complex interactions between site constraints and silvicultural options to improve establishment success and tree growth. Good practice guidance is web-delivered by providing recommended options for cultivation, fertilisation and aspects of 'plant quality' after species choice is matched to site constraints.

THE SYSTEM

The EMIS software integrates with the Ecological Site Classification system (ESC: Ray 2001). The ESC DSS uses models to assess tree species dependent upon six Ecological Site Classification (ESC) factors as criteria for testing site-species suitability (Pyatt and Suarez 1997, Pyatt et al. 2001):

- four climatic factors: accumulated temperature, moisture deficit, windiness (by Detailed Aspect Method of Scoring; DAMS; Quine and White 1993) and continentality,
- two soil quality factors: soil moisture regime (SMR) and soil nutrient regime (SNR).

EMIS integrates with the ESC tree species suitability model and provides additional species-specific silvicultural and plant quality guidance (Perks et al. 2006).

Development of an integrated treatment prescription

On selecting the EMIS programme, the user is required to input site-based assessment information. The first input is location, then dominant soil group is chosen from a drop-down list of 14 classes (Figure 1), and their attendant soil types (Kennedy 2002). Underlying lithology is also chosen from a drop-down menu within EMIS: underlying solid lithology can be obtained and input, for Britain, from British Geological Survey (BGS) maps or from the online BGS 'survey data portal'. A user is encouraged to check and input soil information after a comprehensive soil survey at the chosen restock site (Kennedy 2002). Accurate soil based information is imperative as choice of both cultivation and fertilisation regimes are dependent upon correct soil

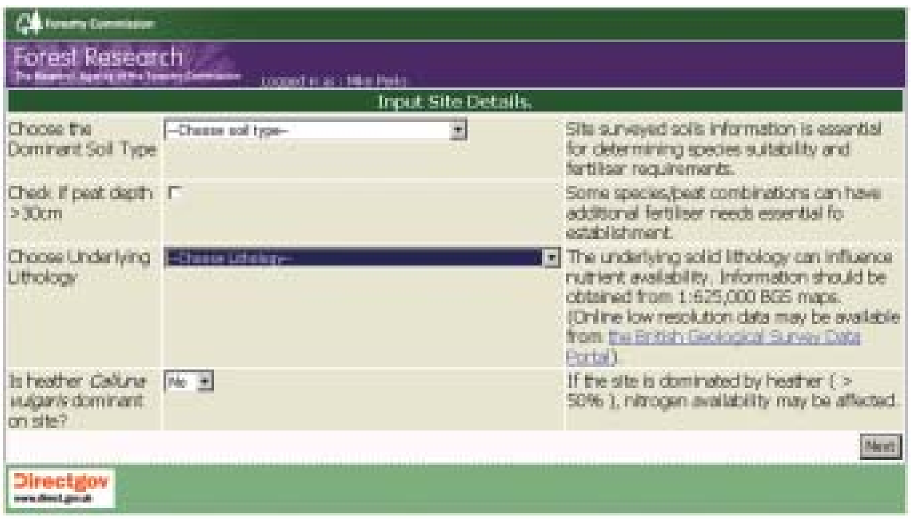


Figure 1. Screenshot of ESC-required EMIS input to constrain species suitability and good practice cultivation and fertilisation advice. Soil type, lithology and Calluna information are presented as user selected drop-down lists, whilst peat depth is a check box (If peat depth >30cm).

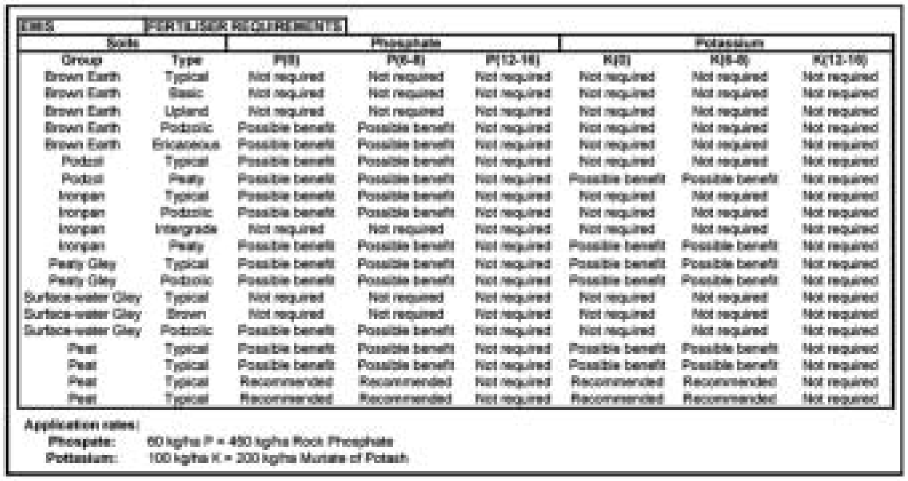
identification (Paterson and Mason 1999, Talyor 1990 a,b). Soil quality (SMR, SNR) is estimated using soil type directly, as modification (refinement) by site vegetation assessment, such as is required by ESC to identify native woodland type, is often not feasible on restock sites due to a lack of vegetation. However this functionality is retained within the EMIS architecture and will allow extension to non-restock sites in future. Further modification (user input) with respect to the presence of heather and the depth of peat are required as these factors are known to affect site fertility and hence alter nitrogen fertilisation guidance (Taylor 1990b; Figure 1). Soils information is therefore the primary driver for good practice advice for cultivation and fertilisation options (Figure 2).

The ESC models are interrogated, then captured site values, for the six constraining environmental site factors (four climatic and two soil factors) are displayed within EMIS. The user can alter any of these set-up parameters using local knowledge. The ESC models are then interrogated and species yields are estimated from accumulated temperature, modified by the most limiting ESC factor. Species suitability (and predicted yield class) are assessed against the continuous suitability functions that have been developed within ESC (Ray et al. 1998) for the ten conifer species and two birch species considered by EMIS for upland restock sites. The EMIS parameterisation therefore operates by calling the relevant ESC models 'behind the scenes'.

Output

Once the user has selected one (or more) species from the suitability screen the EMIS system then presents all existing guidance on appropriate silvicultural options for a site, based on input site-based survey information and the captured constraining factors. Common plant type morphological specifications are provided for seedling trees raised under either cell grown or bare-root stock production systems. Plant morphology (size classes denoted by acceptable height and root collar diameter ranges), and cell sizes for container grown plants are given (cf. Morgan 1999). Target root:shoot ratios (a measure of morphological 'balance' and sturdiness) are also highlighted (see Landis this volume). Information regarding acceptable physiological limits (as are routinely assessed by the physiological plant quality test root electrolyte leakage (REL) assessed at despatch from the nursery) are also presented to the user (e.g. McKay and Mason 1991, McKay 1997, McKay and Howes 1996, Morgan 1999). As the development and validation of other methods of plant vitality assessment occur, such as shoot electrolyte leakage (O'Reilly and Keane 2002, Brønnum 2005), chlorophyll fluorescence (Perks et al. 2001, 2004) or molecular techniques for identifying the development of cold hardiness (Joosen et al. 2006), information regarding these options can be introduced to the system database.

In Figure 3 we have used expert knowledge and unpublished experimental data to present guidance regarding acceptable planting



EMIS — FERTILISER REQUIREMENTS

Soils		Phosphate			Potassium		
Group	Type	P(0)	P(6-8)	P(12-16)	K(0)	K(6-8)	K(12-16)
Brown Earth	Typical	Not required	Not required	Not required	Not required	Not required	Not required
Brown Earth	Basic	Not required	Not required	Not required	Not required	Not required	Not required
Brown Earth	Upland	Not required	Not required	Not required	Not required	Not required	Not required
Brown Earth	Podzolic	Possible benefit	Possible benefit	Not required	Not required	Not required	Not required
Brown Earth	Ericaceous	Possible benefit	Possible benefit	Not required	Not required	Not required	Not required
Podzol	Typical	Possible benefit	Possible benefit	Not required	Not required	Not required	Not required
Podzol	Peaty	Possible benefit	Possible benefit	Not required	Possible benefit	Possible benefit	Not required
Ironpan	Typical	Possible benefit	Possible benefit	Not required	Not required	Not required	Not required
Ironpan	Podzolic	Possible benefit	Possible benefit	Not required	Not required	Not required	Not required
Ironpan	Intergrade	Not required	Not required	Not required	Not required	Not required	Not required
Ironpan	Peaty	Possible benefit	Possible benefit	Not required	Possible benefit	Possible benefit	Not required
Peaty Gley	Typical	Possible benefit	Possible benefit	Not required	Possible benefit	Possible benefit	Not required
Peaty Gley	Podzolic	Possible benefit	Possible benefit	Not required	Possible benefit	Possible benefit	Not required
Surface-water Gley	Typical	Not required	Not required	Not required	Not required	Not required	Not required
Surface-water Gley	Brown	Not required	Not required	Not required	Not required	Not required	Not required
Surface-water Gley	Podzolic	Possible benefit	Possible benefit	Not required	Not required	Not required	Not required
Peat	Typical	Possible benefit	Possible benefit	Not required	Possible benefit	Possible benefit	Not required
Peat	Typical	Possible benefit	Possible benefit	Not required	Possible benefit	Possible benefit	Not required
Peat	Typical	Recommended	Recommended	Not required	Recommended	Recommended	Not required
Peat	Typical	Recommended	Recommended	Not required	Recommended	Recommended	Not required

Application rates:
Phospate: 60 kg/ha P = 450 kg/ha Rock Phosphate
Pottasium: 100 kg/ha K = 200 kg/ha Muriate of Potash

Figure 2. Screenshot of the EMIS good practice guidance database sheet for Phosphate and Potassium applications, during the establishment phase, for lodgepole pine (Pinus contorta). The specific guidance for an individual soil group and type is delivered to the user as web-based and optional .pdf output.

windows for container-grown seedling trees in the UK.

Acceptable planting windows in upland Britain, which depend on plant specifications and the climate zone of the planting site (captured from an accumulated temperature map: see Figure 3, Morgan 1999) are also presented in tabulated format. Climate zone is divided into three broad categories of accumulated temperature where a warm site has greater than 1350 day degrees above 5°C, an intermediate site type has 1050-1350 day degrees above 5°C, and a cold site experiences less than 1050 day degrees above 5°C. Guidance on acceptable planting windows has been developed from operational experience allied to the interpretation of post-lift and post-storage REL tests as a measure of plant vitality for bare-root seedlings. For containerised stock, guidance is based primarily on expert knowledge as extensive research on application and interpretation of measures of plant quality and their correlation to outplanting performance is lacking. The period identified for use of cold-stored stock relates to the period of soft shoot growth in non cold-stored material, though these windows will vary slightly dependent on nursery location, species, seedling age and climate. Furthermore, plant cold tolerance at time of storage, which is dependent on previous climatic conditions, has a direct influence on the maximum acceptable storage duration, and therefore appropriate windows for planting of this stock type. Likewise, decisions regarding appropriate planting windows in the winter months and extension of planting into June and July should be taken based on examination of local site conditions. Moist (spring/summer) and unfrozen (winter) soil is required to ensure good establishment success of container-grown trees. Acceptable on-site storage periods for cell grown stock are considerably longer where plants can be left standing on a free draining substrate, though watering during extended storage periods is essential.

The EMIS web-browser interface delivers all the appropriate guidance whilst the user can also obtain the output in pdf format, for any number of scenario runs.

Implementation

During development, linkages between EMIS modules and among tools developed within the EMIS framework architecture were considered using the Simile scheme. EMIS alone has been developed with reference to approximately forty technical and scientific publications regarding site-species suitability and the attendant silvicultural management options. By delivering EMIS as a web application, maintenance is reduced as the software and data are held centrally; potential users simply require a web browser. To provide GIS interoperability, which in the Forestry Commission is based on Microsoft.NET technology, some functionality was exposed as document-literal wrapped web services (Butek 2003). Inclusion of this

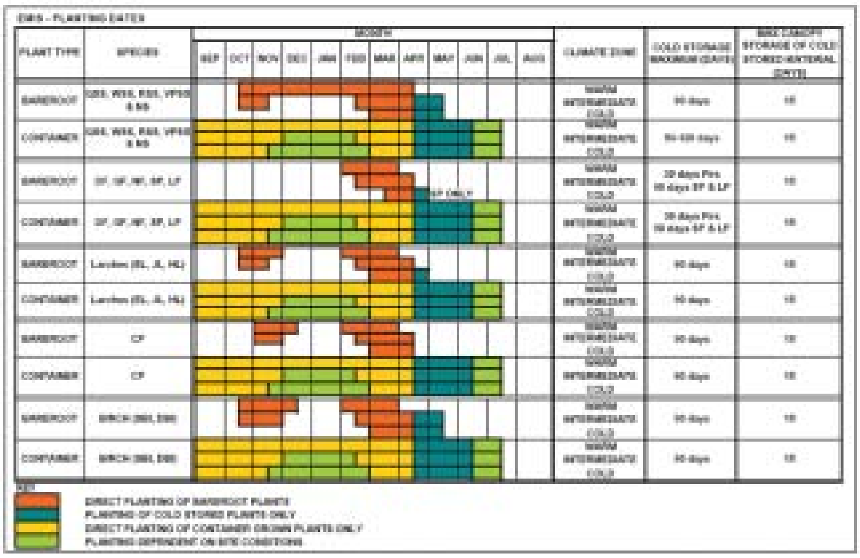


Figure 3. Screenshot of the EMIS good practice guidance database sheet for acceptable planting windows. The specific guidance for a specific species is delivered to the user as web-based and optional .pdf output. Species codes are as in Morgan (1999).

technology will enable EMIS to deliver decision support to both strategic (i.e. spatially through GIS) and small-scale users, within the British forestry sector.

Interoperability

A key to effective decision support for ecosystem management is the interoperability of a variety of systems allowing components to co-operate by exchanging data. EMIS displays interoperability at software and model level with the site classification DSS ESC. Linkage with the Hylobius Management Support System (HylobiusMSS: Moore 2004) and Herbicide Advisor tool (Thomson and Willoughby 2004) are in development.

Operational scale and use

EMIS has been designed initially for use at the stand scale. Within the British national forest estate a spatial (GIS) planning tool 'Forester GIS' has been developed (Suarez et al. 2003) as an extension to ArcView-GIS platform (ESRI, Redlands, California). The development of ESC as an extension to ArcView-GIS has been demonstrated, allowing the suitability of tree species to be analysed spatially using the same six site factors (Clare and Ray 2001). In recent trials, remote calls from the GIS system to EMIS modules have provided 'proof-of-concept' of the interoperability of these tools, thereby enabling a spatial landscape-scale delivery of good practice guidance to the forest planner in the future.

Whilst experienced foresters will have appropriate species, plant types and silviculture in mind when restocking sites, EMIS may be consulted to provide a check, the added-value being that any new research or guidance can be centrally updated. Forest planners may consider inappropriate species (e.g. for landscaping reasons) and EMIS would identify such instances. The guidance ensures suitable silviculture, appropriate species with desireable yields are achieved to confrom with the requirements of 'The UK Woodland Assurance Scheme' (Anon. 2000).

Future developments

The development of web-based establishment silviculture and plant quality guidance for Irish conditions is possible using existing standards (Forest Service 2000), published information regarding acceptable nursery tree physiological limits (O'Reilly et al. 2001, 2002; O'Reilly and Keane 2002), seedling morphology (Thompson and Lowe 1999a, b) and silviculture (Horgan et al. 2004). Such guidance can be linked to the application of expert knowledge, where published data is unavailable, and spatial (climate) data such as are available from the Environmental Protection agency (McGrath et al. 2005).

The non-spatial EMIS decision support tool described here is in an advanced stage of development, and will be released in 2006, following testing by research and field specialists. It is intended that the silvicultural management options will be evaluated against a set of sustainability criteria, which will be developed and applied by an expert panel of stakeholders, in order that the user may more clearly define and balance the ecological and production objectives that forest management must meet in the 21st century. Furthermore, EMIS can utilise the ESC models to provide species-specific predictions of species suitability under future climate change scenarios, provided by the UK Climate Impacts Programme (Hulme et al. 2002), which are outwith the normal experiential knowledge of foresters. In Ireland existing future climate scenarios are available (McGrath et al. 2005) and development of guidance and scenario testing of species choice with changing climatic conditions could also be implemented.

REFERENCES

Anon. 2000. *United Kingdom Woodland Assurance Scheme.* Forestry Commission, Edinburgh.

Anon. 2004. *The UK Forestry Standard. The Government's approach to sustainable forestry.* 2nd Edition. Forestry Commission and Department of Agriculture for Northern Ireland. Forestry Commission, Edinburgh.

Bell, S. 1998. *Forest design planning: a guide to good practice.* Forestry Commission Practice Guide 12, 76pp. HMSO, London.

Brønnum, P. 2005. Assessment of seedling storability of *Quercus robur* and *Pinus sylvestris.*

Scandinavian Journal of Forest Research 20, 26-35.

Butek, R. 2003. Which style of WSDL should I use? IBM Developer Works. www.ibm.com/developerworks/webservices/library/ws-whichwsdl/

Clare, J. and Ray, D. 2001. *A spatial model of Ecological Site Classification for forest management in Britain*. In: Konecny. M. (ed.) Proceedings of the 4th AGILE conference on Geographic Information Science, Brno, Czech Republic, April 19–21.

Forest Service. 2000. *Forestry Schemes Procedures and Standards Manual*. Department of the Marine and Natural Resources (Ireland). November 2000. p34.

Horgan, T., Keane, M., McCarthy, R., Lally, M. and Thompson. D. 2004. *A guide to forest tree species selection and silviculture in Ireland.* O'Carroll, J. (ed). COFORD, Dublin. 256pp.

Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. 2002. *Climate change scenarios for the United Kingdom: the UKCIP02 Technical Report*. Tyndall Centre, UEA, Norwich. 120pp.

Joosen, R.V.L., Lammers, M., Balk, P.A., Bronnum, P., Konings, M.C.J.M., Perks, M., Stattin, E., Van Wordragen, M.F and Van Der Geest, A. (Lonneke) H.M. 2006. Correlating gene expression to physiological parameters and environmental conditions during cold acclimation of *Pinus sylvestris* (L.), identification of molecular markers using cDNA microarrays. *Tree Phsiology* (in press).

Kennedy, F. (2002) The identification of soils for forest management. Forestry Commission Field Guide, 56pp. HMSO, London.

Lane, M.B. and McDonald, G. 2002. Towards a general model of forest management through time: evidence from Australia, USA, and Canada. *Land Use Policy* 19, 193–206.

Mason, E.G. 1997. Planning forest establishment operations with a computerised decision-support system: a case study analysis of decision-making over a full rotation. *New Zealand Journal Forest Science* 26, 222–234.

McGrath, R., Nishimura, E., Nolan, P., Semmler, T., Sweeney, C. and Wang, S. 2005. *Climate Change: Regional Climate Model Predictions for Ireland.* Environmental Protection Agency, Ireland. 52pp.

McKay, H.M. 1997. A review of the effect of stresses between lifting and planting on nursery stock quality and performance. *Silva Fennica* 13, 369-399.

McKay H.M. and Howes R. 1996. *Recommended plant type and lifting dates for direct planting and cold-storage of bare-root Douglas fir in Britain.* Forestry Commission Research Information Note 284, 5 pp.

McKay H.M. and Mason W.L. 1991. Physiological indicators of tolerance to cold-storage in Sitka spruce and Douglas fir seedlings. *Canadian Journal of Forest Research* 21, 890-901.

McKay, H.M. and Mason, E.G. 2001. Modelling the effects of nursery and site managementon the early performance of *Picea sitchensis* (Bong.) Carr. *New Forests* 22,111–131.

Moore, R. 2004. *Managing the threat to restocking posed by the large pine weevil,* Hylobius abietis*: the importance of time of felling of spruce stands.* Forestry Commission Information Note 61, 4pp. HMSO, London.

Morgan, J.L. 1999. *Forest tree seedlings: best practice in supply, treatment and planting.* Forestry Commission Bulletin 121, 44pp. HMSO, London.

O'Reilly, C. and Keane, M. 2002. *Plant quality: what you see is not always what you get.* COFORD Connects, Reproductive Material Note No. 6. 4pp.

O'Reilly, C., Baraldi, A., Carbral, R., Harper, C., Mortazavi, M. and Keane, M. 2001. *Effect of physiological condition at time of lifting on cold-storage tolerance and field performance of important conifer and broadleaf species.* COFORD Connects Reproductive Material No. 2. 4pp.

O'Reilly, C., Keane, M. and Morrissey, N. 2002. *The importance of plant size for successful forest plantation establishment.* COFORD Connects Reproductive Material No. 5. 5pp.

Paterson, D.B. and Mason, W.L. 1999. *Cultivation of soils for forestry.* Forestry Commission Bulletin 119, 85pp. HMSO, London.

Perks, M.P., Osborne, B.A. and Mitchell, D.T. 2004. Rapid predictions of cold tolerance in Douglas fir seedlings using chlorophyll fluorescence after freezing. *New Forests* 28, 49-62.

Perks, M.P., Monaghan, S.M., O'Reilly, C., Osborne, B.A. and Mitchell, D.T. 2001. Chlorophyll fluorescence characteristics, performance and survival of freshly lifted and cold-stored Douglas fir seedlings. *Annals of Forest Science* 3, 225-235.

Perks, M.P., Harrison, A.J. and Bathgate, S.J. 2006. *Establishment Management Information System [EMIS]: delivering good practice advice on tree establishment in the uplands of Britain*. In: Reynolds, K.M., Ray, D and Thomson, A.J. (eds.) Proceedings of the IUFRO conference 'Sustainable forestry in theory and practice:

recent advances in inventory and monitoring,statistics and modelling, information and knowledge management and policy science', CABI International (in press).

Pyatt, D.G., Ray, D., and Fletcher, J. 2001. *An Ecological Site Classification for Forestry in Great Britain.* Forestry Commission Bulletin 124, 74pp. HMSO, London.

Pyatt, D.G. and Suarez, J.C. 1997. *An Ecological Site Classification for Forestry in Great Britain: with special reference to Grampian Scotland.* Forestry Commission Technical Paper 20, 96pp. HMSO London.

Quine, C.P. and White, I.M.S. 1993. *Revised windiness scores for the windthrow hazard classification: the revised scoring method.* Research Information Note 230. Forestry Commission, Edinburgh.

Rauscher, H.M., Lloyd, F.T., Loftis, D.L. and Twery, M.J. 2000. A practical decision-analysis process for forest ecosystem management. *Computers and Electronics in Agriculture* 27, 195–226.

Ray, D. 2001. *Ecological Site Classification Decision Support System (v.1.2).* Forestry Commission, Edinburgh.

Ray, D. and Broome, A. 2003. *Ecological Site Classification: supporting decisions from the stand to the landscape scale.* In: Forest Research Annual Report 2001-2002. HMSO, London.

Ray, D., Reynolds, K., Slade, J. and Hodge, S.J. 1998. *A spatial solution to Ecological Site Classification for British forestry using Ecosystem Management Decision Support.* In: Abrahart, R.J. (ed.) Proceedings of the 3rd International Geocomputation Conference, Bristol University, September 1998.

Smith, D.M. 1986. *The Practice of Silviculture.* 8th Edition. 527 pp. Wiley, New York.

Smith, S.A. and McKay, H. 2002. *Nutrition of Sitka spruce on upland restock sites in northern Britain.* Forestry Commission Information Note 47, 6pp.

Suárez, J., Smith, S. and Ditchburn, B. 2003. The use of GIS in forestry. *Quarterly Journal of Forestry* 97, 265-270.

Sutton, R.F. 1993. Mounding site preparation: A review of European and North American experience. *New Forests* 7, 151-192.

Tabbush, P.M. 1988. *Silvicultural principles for upland restocking.* FC Bulletin 76. Forestry Commission. HMSO, London. FC Bulletin 76, 22pp.

Taylor, C.M.A. 1990a. *The nutrition of Sitka spruce on upland restock sites*. Forestry Commission Research Information Note 164, 3pp. HMSO, London.

Taylor, C.M.A. 1990b. *Forest fertilisation in Britain.* Forestry Commission Bulletin 95, 23pp. HMSO, London.

Thompson, B. and Lowe, R. 1999a. *Sitka spruce planting stock: does size make a difference?* Coillte R&D - Research Update No. 1.

Thompson, B. and Lowe, R. 1999b. *Effect of plant size on field performance of Douglas fir, Japanese larch and ash.* Coillte R&D - Research Update No. 2.

Thomson, A.J. and Willoughby, I. 2004. A web-based expert system for advising on herbicide use in Great Britain. *Computers and Electronics in Agriculture* 42, 43–49.

Turban, E. and Aronson, J. 2000. *Decision Support Systems and Intelligent Systems.* 6th Edn., Prentice-Hall, NJ.

Willoughby, I. and Dewar, J. 1995. *The use of herbicides in the forest.* Forestry Commission Field Book 8. HMSO, London.

Willoughby, I., Evans, H., Gibbs, J., Pepper, H., Gregory, S., Dewar, J., Nisbet, T., Pratt, J., McKay, H.M, Siddons, R., Mayle, B., Heritage, S., Ferris, R. and Trout, R. 2004. *Reducing pesticide use in forestry.* Forestry Commission Practice Guide 15, 141pp. HMSO, London.

Forest Service requirements for nursery stock

John Connelly

Successive governments for a considerable period have adopted an expansionist policy towards forestry in Ireland. After the foundation of the state, resources were mainly channelled into state forestry, but private forestry was also encouraged through the introduction of planting grants in 1932. However, it was not until the introduction of the Western Package in 1981 and particularly the introduction of annual premiums in 1989 to compensate for income foregone, that private forestry began to develop.

Irish nurseries produce approximately 75 million plants annually to service the afforestation programme, the reforestation programme, the Native Woodland Scheme planting and other schemes. They now produce approximately 90% of the total plant requirement.

To put the current afforestation and reforestation programmes into perspective it is necessary to consider the 2004 programme and the species content. The final afforestation outturn for 2004 was just short of 10,000 ha - 50% of the target. However, a full reforestation programme of over 9,000 ha was achieved. It is likely that the afforestation programme will increase slightly for 2005 with the reforestation decreasing to 8,000 ha.

For both programmes there is currently a high demand for quality broadleaf transplants. This is as a result of the EU imposed broadleaf requirement of 30% of new planting to be achieved by 2006, and also the certification requirement on Coillte which requires that they increase the broadleaf forest in their estate from 4 to 10%. A further consideration is the better quality of land available for afforestation in the private sector and the higher level of grants for planting broadleaves.

The broadleaf component of the 2004 private afforestation programme was 29%.

Accepting that broadleaf stocking rates are much greater than that for conifers, the increase in the broadleaf plant requirement over the last number of years has put increased pressure on nurseries to produce broadleaf growing stock.

Government policy is committed to sustainable forestry and as a result there are environmental, economic and social elements to be considered in the current planting programme.

There is one important common factor between the major stakeholders involved in the planting programme: the landowner, the forestry contractor and the Forest Service. All three players want to see satisfactory end results, with good quality plantations established which in time will fulfil an important objective of the national planting programme which is the production of raw material for industry.

PLANT QUALITY

The basic building block of plantation forestry is quality plants, and while the great majority of plants used are bare-rooted transplants, both freshly lifted and from cold-store facilities, there is likely to be an increase in demand for containerised planting stock in the future as we move towards greater mechanisation of the planting process.

While there are often diverging opinions on the ideal size or type of plant which should be used on a particular site, there is generally agreement among foresters regarding plant quality. Quality transplants should have the following characteristics:

(a) A straight stem with a definite leader.
(b) A well balanced stem with healthy foliage and a good fibrous root system.
(c) A specified height to provide for size above ground when planted.
(d) A specified root collar diameter to provide for hardiness.
(e) An accepted root/shoot ratio.
(f) Age must not exceed a specified maximum.

The quality limits set by the Forest Service in respect of age, root collar diameter and stem size for the most common species are set out in Tables 1 and 2.

PROVENANCE REQUIREMENTS

The importance of correct provenance choice in a forestry programme cannot be overstated. The Irish afforestation programme has suffered greatly in the past from the use of incorrect provenance sources. Examples include Lulu Island lodgepole pine, Scandinavian birch and Scots pine, while more recently difficulties have been experienced with some European provenances of oak, ash and cherry.

When available and where possible, home-collected seed from registered Irish seed stands should be the first choice at all times. The seed origins/provenances acceptable to the Forest Service for grant purposes are shown in Table 3.

Table1: Broadleaves - Quality requirement limits for transplants.

Species	Maximum Age (years)	Min. Collar Diameter (mm)	Stem Height (cm)
Ash	3 4	7 12	50-75 60-90
Oak/Spanish chestnut/Beech	4 4 5	6 7 9	45-75 55-70 70-85
Sycamore	3	7	45-75
Alder	3	4	30-60
Other broadleaves	5	4	40-75

Table 2: Conifers - Quality requirement limits for transplants

Species	Maximum Age (years)	Min. Collar Diameter (mm)	Stem Height (cm)
Sitka spruce	4	6 (4*)	31-65 (20-30*)
Norway spruce	4	6 (4*)	31-50 (20-30*)
Lodgepole pine	2	3	10-20
Scots pine	3	4	20-40
Corsican pine	3	3	10-30
Japanese larch	3	5 (4*)	36-60 (25-35*)
European and hybrid larch	3	5	35-60
Douglas fir	4	8	40-60
Western red cedar/Western hemlock	4	4	25-45

(*) These are Size 2 Category Plants and apply only to Sitka spruce, Norway spruce and Japanese larch. They are suitable for sites without the potential for the vigorous growth of competing vegetation, provided the site is not liable to frost.

Table 3: Provenances of conifer and broadleaf species approved by the Forest Service and acceptable for grant support in Ireland.

Conifer species	
Sitka spruce (*Picea sitchensis*)	Registered Irish and British seed stands and material from Danish and British seed orchards. Seed imports under EU derogation from the Queen Charlotte Islands, coastal Washington and Oregon. Rooted cuttings derived from genetically improved Washington or Queen Charlotte Island material.
- most sites (low to mid elevation sites of less than 300 m, except low lying midland bogs)	South Washington and North Oregon origins.
- cold frost prone sites (above 300 m elevation and low lying midland bogs)	Queen Charlotte Islands (QCI) origins.
Norway spruce (*Picea abies*)	Registered Irish and British seed stands and registered seed stands in the low elevations of Denmark and Germany (north of Frankfurt). Seed imports under EU derogation from Sudetan and Beskid regions of the Czech Republic, Tatra Mountains of Slovakia, north east and lowlands of south Poland.
Serbian spruce (*Picea omorika*)	Irish and British stands and seed imports from Serbia.
Lodgepole pine (*Pinus contorta*)	Irish and British seed orchards and stands.
- in mixture with Sitka spruce	Alaskan and North Coastal (including QCI and Vancouver Island origins).
- exposed, infertile sites	QCI, Vancouver Island and Interprovenance hybrids.
- less exposed, mineral soils	Interprovenance hybrids, Lower Skeena River (Terrace, Kalun Lake and Hazelton) and South Coastal seed orchard material.
Scots pine (*Pinus sylvestris*)	Irish and Scottish seed orchards and registered seed stands.
Austrian pine (*Pinus nigra var. nigra*)	Registered Irish and British seed stands.
Corsican pine (*Pinus nigra var. maritima*)	Registered Irish, British and Corsican seed stands.
Monterey pine (*Pinus radiata*)	Guadalupe Island (Mexico) or seed stands derived from this origin and home-grown Irish healthy, non-yellowing trees.
Douglas fir (*Pseudotsuga menziesii*)	Registered Irish and British seed stands and seed imports under EU derogation from coastal Washington and northern Oregon.
Grand fir (*Abies grandis*)	Irish and British seed stands and imports from Olympic peninsula, Puget sound (Washington), Washington and Oregon coast range mountains and Vancouver Island.
Western hemlock (*Tsuga heterophylla*)	Irish and British seed stands and seed imports from Puget Sound region of Washington state and the coast range and Cascade Mountains of Washington and Oregon.
Western red cedar (*Thuja plicata*)	Irish and British seed stands and seed imports of seed from Vancouver Island (British Columbia) and coastal Washington and Oregon.
Japanese larch (*Larix kaempferi*)	Registered Irish, British and European seed stands. Seed imports under EU derogation from Hokaido Island (Japan) and stands derived from this source as well as material from the Suwa region of the Nagano Prefecture (on Honshu Island) between 1,300 and 2,000 m elevation and seed stands derived from these sources.
European larch (*Larix decidua*)	Registered Irish, British, German (Schlitz) and low elevation Austrian (Wienerwald) seed stands. Seed imports under EU derogation from Southern Poland, Czech Republic (Sudetan Mountains) and Slovakia (Tatra Mountains).
Hybrid larch (*Larix eurolepis*)	Irish, British, French, Belgian, Dutch, Danish, German, Swedish and Polish seed orchards.
Monterey cypress (*Cupressus macrocarpa*)	Irish and British seed stands and seed imports from coastal southern Oregon and northern California.
Coast redwood (*Sequoia sempervirens*)	Irish and British seed stands and seed imports from coastal southern Oregon and northern California.
Lawson cypress (*Chamaecyparis lawsoniana*)	Irish and British seed stands and imports from coastal southern Oregon and northern California.

Broadleaved species	
Pedunculate oak (*Quercus robur*)	First Choice: Registered Irish material. Otherwise registered British (English and Welsh), French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands.
Sessile oak (*Quercus petraea*)	First Choice: Registered Irish material. Otherwise registered British (English and Welsh), French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands.
Red oak (*Quercus rubra*)	Registered Irish, British, French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands.
Beech (*Fagus sylvatica*)	Registered Irish, British, French (north of Paris), Belgian, Dutch, German (north of Frankfurt) seed stands.
Ash (*Fraxinus excelsior*)	First Choice: Irish native material. Otherwise Registered British (English and Welsh), French (north of Paris), Belgian, Dutch, Danish German (north of Frankfurt) seed stands.
Sycamore (*Acer pseudoplatanus*)	Irish, British (English and Welsh), French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands.
Norway maple (*Acer platanoides*)	Irish, British (English and Welsh), French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands.
Common alder (*Alnus glutinosa*)	First Choice: Irish native material. Otherwise British, French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands.
Cherry (*Prunus avium*)	First Choice: Irish native material. Otherwise British, French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands. Not seeds resulting from fruit processing.
Southern beech (*Nothofagus procera/N.obliqua*)	Irish and British seed stands and *Nothofagus procera* imported from Chile (Malleco and Llanquihue). *Nothofagus obliqua* from Chile (Frutillar).
Lime (*Tilia cordata/T.platyphyllos*)	Irish, British, French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt) seed stands.
Spanish chestnut (*Castanea sativa*)	French seed orchard material (not nuts collected for consumption).
*Birch (*Betula pubescens*) (*Betula pendula*)	First choice: Irish native material. Otherwise British materal.
*Rowan (*Sorbus aucuparia*)	First choice: Irish native material, Otherwise British materal.

* Up to 5% of these species may be planted for a variety of environmental enhancing reasons.

EU FOREST REPRODUCTIVE MATERIAL REGULATIONS

On 1 January 2003 a new single EU Directive, Council Directive 1999/105/EC on the marketing of forest reproductive material, was introduced to all EU Member States.

Forest reproductive material (FRM) is a collective term used to describe seeds, plants and other propagating material which are important for forestry purposes. The new marketing directive updates the legislation to take account of the accession of new Member States since 1975, the internal market, and scientific advances including the availability of new material. It is also compatible as far as possible with the revision of the current Organisation for Economic Co-operation and Development (OECD) scheme for the control of FRM moving in international trade. In Ireland, the Forest Service, Department of Agriculture and Food, is the national authority with responsibility for the implementation of the directive. The new directive has been transposed into Irish legislation by the European Communities (Marketing of Forest Reproductive Material) Regulations 2002.

The new directive applies to production with a view to marketing of species which are important for a range of forestry purposes including, but not exclusively, the production of wood. It covers a much wider range of species important for forestry in Ireland, including ash, alder, birch, sycamore, cherry and lodgepole pine. Significantly, a new category of material 'Source Identified' is included. This is FRM derived from basic material which may be either a seed source or stand located within a single region of provenance. This will allow collection and marketing of seed from outside of 'Selected' registered sources, subject to official control and labelling.

A key principle of the directive is that FRM remains clearly identifiable through the entire process, from collection to delivery to the end user. Under the new directive there is a legal requirement for suppliers of FRM throughout the EU to be officially registered. All seed collectors, seed suppliers, nurseries, plant suppliers/brokers etc. must be registered with the Forest Service. All seed collections must be notified in advance following which a Master Certificate of Provenance will be issued. Seed and plants should only be purchased from registered suppliers and material must be accompanied by an approved Supplier's Document. These rules provide traceability and assurance to the end user regarding the origin and suitability of the planting stock. Details of the provenance/origin of planted material also provide an essential forest management record.

For the purpose of the Forest Service grant schemes, all planted material must be covered by a Supplier's Document in the form of a Provenance Declaration Form.

A Provenance Declaration Form – Supplier's Document must be completed for all the species listed in Table 3. Only the origins/provenances listed in this table are acceptable for grant purposes. Part A of the Provenance Declaration Form is completed by the Nursery/Supplier supplying the plants. The Nursery/Supplier must declare that the origin/provenance complies with the accepted list of origins/provenances. Part B of the form is completed by the Contractor or Applicant applying for the grant.

Plant quality – What the grower needs

John O'Reilly

INTRODUCTION

I agreed to present this paper because I feel foresters in the private sector, with their extensive experience in the field, have much to offer on this topic and should become more involved in seminars, meetings and workshops. I then, however, got a bit nervous when I realised I would be talking about plant quality to an audience that would consist of the cream of the nursery sector in Ireland, if not the world, and I wondered what could I tell these people about plant quality. However, to begin I need to clarify two terms.

Firstly I feel I need to clarify the word 'grower'. A grower in this instance refers to the forester or private forestry company utilising plants supplied by the nursery sector to establish a plantation on behalf of a farmer or investor.

The second issue which I wish to clarify is the understanding of the words 'plant quality'. In my opinion plant quality only partially refers to physical appearance, size or straightness but it primarily refers to the essence of the tree, its genetic make-up and the level of confidence a forester can have in its source and traceability.

When I actually thought about this topic I found that every grower or forester within Green Belt has issues with plant quality. I should know as I tend to get their frustrations on this topic regularly. I will therefore concentrate on the issues raised by our foresters on a regular basis in relation to plant quality and the overall standard of planting stock available generally. The issues our foresters have with plant quality are not with the physical attributes of the plants provided by the nursery sector today but are more to do with broader issues that are possibly more difficult to solve.

For the purpose of this paper I have concentrated on figures and issues within Green Belt alone rather than the entire afforestation sector. However, our company has approximately 40% market share, so our concerns can realistically be taken as being representative of the overall afforestation market.

Green Belt has planted almost 20 million trees in the last two years, representing 17,000 acres of new plantation. The responsibility is on us to plant the best provenances available, and to establish quality plantations that fulfill the principles of sustainable forest management (SFM), the needs of the plantation owner, and the needs of future markets is immense and is paramount to everything else we do. It is only when you quantify the areas and the tree numbers, and add these to the fact that these trees are going to be here for 35 to 120 years minimum, that you realise the implications of what we are doing. The importance of plant quality can therefore never be understated.

Our issues with plant quality are:

- Confidence;
- The conifer issue;
- The broadleaf issue.

I will not be concentrating on other issues such as whether plants achieve specific size categories or have certain physical attributes as outlined by others, as these specifications are predominately met anyway.

CONFIDENCE

I would have to say that the biggest issue people I have spoken to have in relation to plant quality is confidence or more specifically the lack thereof. This lack of confidence is not with the nursery manager or with the physical qualities of the plant leaving the nursery. This lack of confidence goes back to the provenance/seed source stage.

Whilst reviewing the literature one quote regularly appeared. It reads:

> *'The use of sound seed from stands of high inherent quality is widely recognized as the best means of ensuring fast growing and healthy plantations capable of yielding good quality wood. Seed that is guaranteed to have been collected in*

seed orchards or in selected seed stands or seed production areas may be slightly more expensive than wild seed but additional costs add little to newly established plantations'.

We would like to believe that this is what happens but we base a lack of confidence with the system on the general poor performance of a proportion of broadleaf crops whilst using plants grown from accepted continental provenances and home-collected seed. If a national survey of our broadleaf plantations were to take place and these plantations were quality rated from 1 to 10 I believe the results might not be as good as we would expect.

Foresters wonder if vast proportions of seed are collected not from within selected stands of high genetic quality but rather from thinnings or individual trees that are selected by the quantity of seed they produce rather than quality. I am sure I will be told that this thinking pattern is incorrect but, as I have said before, this fear exists on the ground. The relevance of this issue, particularly to the nursery sector and to the forestry sector in general, is that foresters make the species selection on the ground, and if they are uncomfortable with certain species because they mistakenly believe things are not what they should be, then you will get dramatic reductions in their use. For example, the change in pattern of sycamore and alder planted by Green Belt in the 1999/00 planting season compared to 2004/05. In the 1999/00 planting season equal numbers of sycamore and alder were planted. However, in the 2003/04 planting season there was four times more alder planted than sycamore, while in the 2004/05 planting season there was another 76% drop in the number of sycamore planted, while there was a corresponding increase in the number of alder planted. There is now 17 times more alder planted than sycamore, which is a dramatic change over a very short period and this change had nothing to do with the physical appearance of the sycamore plant. The reason for this is simple, a loss of confidence in sycamore's ability to perform in the field which is based on an assumption that incorrect provenances are being used. However, there are no scientific data to back up this assumption. This has lead to a significant reduction in the utilization of sycamore plants with foresters substituting sycamore in a lot of cases with alder, ash or Sitka spruce.

THE CONIFER ISSUE

The second issue our growers have with plant quality is with our conifers. There are two main issues.

Plant quality

We have undoubtedly become the masters of growing Sitka spruce to 30-60 cm in vast quantities with a nice blue green healthy colour. We now need improvements in the production of other species like Scots pine and Douglas fir. Issues like shoot/root ratio, 'J-rooting' and optimum size still need to be addressed in these species. Survival in the field can still be very variable and foresters find this an unacceptable risk.

It is an accepted fact that we, as a company and as an industry, should be planting more Douglas fir because of its superior wood quality. The main reason for avoiding it as a species is, of course, due to its susceptibility to deer, but production issues such as size and survival rates still worry foresters who tend to avoid these species on the ground. This in turn may lead to alternative species selections on sites that may not be suitable for Sitka spruce or broadleaves, yet they may be planted on these sites.

Foresters need to be confident in species like Douglas fir but I believe they would still not plant Douglas fir even if deer fencing was grant aided due to fears about plant quality. Green Belt planted 6,000 Douglas fir last year out of a total planting programme of 8.75 million plants.

Table 1. Comparison between number of sycamore and alder planted by Green Belt 1999/20 planting season and number planted in 2004/05

Years	1999/2000	2003/2004	2004/2005
Sycamore	600K	300K	70K
Alder	600K	1.2 million	1.19 million

A minuscule total by any standard and the numbers were rather similar for the previous planting season. The same quality issues can be applied to Scots pine, our native conifer. If Scots pine was not planted in mixtures with oak its uptake would indeed be poor. There are also provenance issues with Scots pine that need to be addressed. My view is that we should, as foresters, be planting more Scots pine.

Research in the field and putting research findings into practice

The example I use here is Queen Charlotte Island (QCI) vs Washington provenances of Sitka spruce and the practices in Coillte as opposed to the private forestry sector. The private sector prefers QCI sources while the practice in Coillte is to plant predominantly Washington sources. General recommendations are that, for the majority of sites, Sitka spruce of Washington or Oregon origin should be planted in preference to that of QCI.

This is because these sources provide a far better financial return to the grower through increased timber production over a shorter rotation. Research findings have shown increased diameter growth at breast height and increased standing volume of up to 25-37% in Washington stands over QCI after 22 growing seasons.

However, the perception amongst some foresters is different on the ground. Foresters tend to roll from season to season with primarily QCI as their core Sitka spruce source believing Washington to be more susceptible to frost and that it has reduced timber quality because it grows faster.

The literature states that in reality density varies very little in our provenance range, and due to reduced knot frequency (because of greater inter-whorl spacing added to quicker canopy closure) we find that Washington provenances actually produce better quality timber.

If we can reduce rotations and increase timber quality why the dependency on QCI in the private sector? There are two reasons:

(i) People are generally slow to change and they fear increased failure rates due to frost.

(ii) The lack of a clear forum for communication between the different sectors involved in forestry, i.e. Forest Service, Coillte and the private sector, where one could openly discuss the best way forward for the sector as a whole, make advantageous decisions and discuss and share research data and experiences in a co-ordinated fashion. QCI sources can grow well in Ireland, as we all know, but why settle for QCI if Washington or Oregon sources are more productive?

THE BROADLEAF ISSUE

As already stated it is predominately the broadleaf issue that causes the most concern amongst foresters on the ground and is the area where confidence levels in plant quality and seed collection are at their lowest. This fear is based primarily on the performance of our broadleaf crops on the ground. The best way to review the broadleaf issue is to look at each species individually.

Alder (*Alnus glutinosa*)

The use of alder has grown in popularity amongst establishment foresters in recent years. Green Belt planted approximately 1.2 million alder in the 2003/04 season and again in the 2004/05 season. The company currently has no issues with alder, except the availability of desirable sizes. I believe its popularity is based simply on:

- Its ease of good establishment and growth;
- The type of site available for forestry combined with the desire to achieve minimum broadleaf percentages;
- Its wide natural range across Ireland;
- It is a native species and is considered to be less susceptible to deer damage.

Even though issues exist with *Phytophthora* and the image of its timber, I believe it will form a core species within future afforestation programmes, particularly if premia payments in the future are reduced from 20 years to 15 years, which will reduce planting of long rotation broadleaves. In relation to markets I believe that if the supply is there – critical mass, the markets for the timber will develop.

Ash (*Fraxinus excelsior*)

Foresters have refined their site selection for this species and are tending to get the mix of plant quality, site and establishment techniques right. It is therefore ironic that ash has substantially contributed to the main worry growers have with plant quality, i.e. confidence of origin. The introduction of brown bud ash (*Fraxinus augustifolia*) into this country from the continent has been an expensive misadventure. Its removal and replacement has cost the Forest Service a minimum of €600,000 to date, with an aggressive and expensive total eradication programme now considered essential. The grief factor experienced by foresters has been immense but the cost of allowing it to hybridise with native stock of common ash (*Fraxinus excelsior*) would be immeasurable. It is easy to understand why foresters would have concerns when we review the brown bud ash story.

Who was the scoundrel? Did one exist or was this an unfortunate chain of events?

One element concerns me in relation to collecting ash seed and that is that seed production of ash in closed stands is generally poor due to small crown development. Therefore seed collections are almost exclusively made from hedgerow trees and this practice is likely to continue until recently established seed orchards are brought into seed production. I wonder if this factor affects the quality of our plantations, because it definitely affects the confidence of our foresters.

Oak (*Quercus petraea* and *Q. robur*)

Unfortunately oak is still the species that raises the most concerns amongst our foresters. It is difficult to come up with reasons why a native tree can sometimes perform so poorly. Why is it so susceptible to mildew and why does it have such poor form with heavy stag heads appearing in many plantations? When experienced foresters and good sites in combination fail to produce good oak plantations it is only natural that one questions provenance and seed supply. Can we establish nice oak plantations? The answer is yes, but are we producing enough of them?

I should qualify my criticisms of oak by saying that I believe that we are judging our oak plantations far too early and stands seem to be improving with age.

Sycamore (*Acer pseudoplatanus*)

Our foresters have serious problems with sycamore for the following reason. In general there is no faith in the provenances used, even if seed is home collected.

Considering the fact that sycamore is a non-native species of continental origin it is possible that the present naturalized seed source may not be the most suitable for this country and as no provenance trials have been established in Ireland, there is no information on the performance of sycamore sources from its natural range tested under Irish growing conditions.

Beech (*Fagus sylvatica*)

Beech is a species that we are actually happy with from a provenance and plant quality view point. Foresters, I believe, are very conservative on site selection for beech and therefore it only tends to be planted on most suitable sites. Establishment difficulties are a completely different issue and have more to do with experience than plant quality.

Cherry (*Prunus avium*)

Our past experiences with cherry would have tarnished our foresters view on this species and also add fuel to their concerns on provenance. Cherry was heavily promoted in the mid 1990s based on its timber value, relatively short rotation and the fact that it was native and not very susceptible to damage by squirrels. However, the results were very poor and it had major problems with bacterial canker. However, I believe we should learn from our mistakes and not cast cherry to one side. Cherry should be given a second chance with different planting patterns. However, much work is still required in relation to suitable provenances, suitability of sites which should improve forester confidence in this species.

CONCLUSION

To bring things to a conclusion we must, as the title of this paper states, ask ourselves what does the grower want?

I believe the emerging trend in tree species usage over a period of time based on actual experiences on the ground answers this question.

Let us look at the broadleaf usage within Green Belt over the last two seasons in Table 2.

What conclusions can we draw from these figures?

1. There is a definite move towards the use of native broadleaves.
2. There is a definite move towards the use of pioneer species.
3. There is a lack of confidence in the provenances of our exotic broadleaves.

So is it correct to conclude that a grower needs a good quality native tree from a home collected seed source. Personally I believe the answer to this is a resounding 'Yes'.

We must therefore address this issue by:

- Concentrating our forest policy in relation to broadleaves on the establishment of natives.
- We must source more quality native seed across all species.
- We must encourage the work of our national forest seed centre.
- We must view the establishment of native pioneers as positive and as an opportunity to facilitate the establishment of climax native broadleaves like ash and oak.
- We need to establish a strong forum to discuss at regular intervals our species of choice, the reason we choose them and consequently make sound policy decisions for the future.
- And finally, we must never forget that the onus is on all of us, as practising foresters, to work towards getting it right from the start.

Table 2. Broadleaf species planted by Green Belt – season 2003/04 and 2004/05.

Species	Season 2003/04	Season 2004/05
Alder	1.2m	1.19m
Ash	500k	670k
Oak	475k	503k
Syc	300k	70k
Beech	150k	50k
Birch	90k	200k

Container plants and mechanised planting – The way forward?

Dr Mick Keane

INTRODUCTION

The purpose of this presentation is to:

- Provide some of the background information on mechanical planting in Coillte;
- Outline the current equipment available and their capabilities;
- Show some of the results of mechanical planting so far;
- Indicate future developments in the area.

It must be emphasised that the presentation concentrates on mechanised planting on restock sites, using container stock only.

BACKGROUND

Coillte's current restock programme is about 8,500 ha/year, costing between €10 and €15 million. This figure is for direct costs only and does not include staff costs for example. There is constant pressure to reduce this figure and to 'benchmark' our costs/ha with international figures in Europe and beyond. One of the methods examined to reduce costs was to look at alternatives to manual planting. This has already happened in the harvesting area in this country, where, currently, over 95% of operations are carried out mechanically.

CURRENT EQUIPMENT AVAILABILITY

In the same way as Scandinavian manufacturers have been at the forefront of harvesting technology, most of the mechanical planting systems that are capable of planting restock sites have also been designed and manufactured in Sweden and Finland. There are currently three main restock planters available:

- The Lannen FP-160;
- The EcoPlanter;
- The Bracke Planter.

Lannen FP-160

This equipment is designed and manufactured in Finland by Lannen, a company with strong links to the container nursery trade. It is a relatively simple design, with the capability of being attached to many different types of prime mover, e.g. farm tractor, excavator or timber harvester. It is somewhat limited by the fact that it does not cultivate the soil as it plants and a separate piece of equipment would be required to be brought on site if cultivation were required. The current cost of this planting head is approximately €20,000.

▲ *Lannen FP-160 planter.*

EcoPlanter

Designed and built in northern Sweden, the EcoPlanter is now partly owned by Komatsu. This planting head is unique in that it plants two plants simultaneously from a carousel which holds over 200 plants. The planting mechanism is also unusual in that rotors on the planting heads spin at high speed and create two loose cultivated mounds, into which the trees are inserted. An EcoPlanter has been working in this country for approximately three years, with an annual planting programme of over 200 ha. The equipment uses a harvester as its prime mover and the cost of the planting head is €70,000.

Ecoplanter.

Bracke Planter

The Bracke is the best seller of the three, with over fifty units working in Europe alone. The head is excavator-based and plants one plant at a time. The cultivation system used is simply to turn over a sod and plant into the top of the raised mound created. The annual planting programme for the Bracke is approximately 120 ha and, over the past six years, there have been four Brackes working in Ireland at different times. The Bracke head costs €45,000. Both the Bracke planter and the EcoPlanter can spray the plant with insecticide as it is planted.

CONTAINER STOCK

All of the planting systems outlined above use only cell or container grown planting stock. This type of planting stock has played only a minor role in Irish forestry to date, as the preferred option has been for bare-root stock. Container stock has been tested in research trials since the 1970s and some very positive results were found with lodgepole pine in the early 1980s.

A report of a survey of operational planting, published in 1990, suggested that container stock had potential for afforestation sites only. In the mid 1990s, establishment foresters reported some very poor experiences with container stock at that time. Looking back, the small size and a lack of hardening off of the plant were probably responsible for the poor establishment success with this stock.

The recent Coillte order for container stock has been in the region of 3-4 million plants. This is grown either in the Coillte nursery in Clone, Co Wicklow, in other private nurseries in Ireland or in the UK. The cost of container stock in comparison with transplant stock is also a problem. Currently, containerised Sitka spruce costs 80% more than bare-root stock, up from 28% greater in 1989.

MECHANICAL PLANTING IN COILLTE

Most of the interest in mechanical planting has come from contractors who are already involved in site cultivation. Some contractors wish to plant almost year round while others plant as part of an annual cycle of work. These latter contractors plant for part of the year only and spend the rest of the year on cultivation of afforestation or restock sites.

Because drainage cannot be carried out as part of the planting operation, most of the mechanical planting undertaken to date has concentrated on drier sites in east Cork/Waterford, Tipperary, Kilkenny and Wicklow. Although both the EcoPlanter and the Bracke Planter have been used on afforestation sites, the vast majority of sites planted have been restock sites.

In an effort to encourage investment in planting machines, Coillte has offered a three year planting programme to interested contractors. In the past, this has been quite successful and within the last year, three Bracke Planters and one EcoPlanter were working on restock sites in the company. This has changed in

Bracke planter.

recent months and, as of now, there is only one Bracke working. Suitable sites have become scarce and this has implications for plant supply. Container stock needs to be ordered twelve to eighteen months in advance of being used for most species. If plant supplies are not used for mechanical planting, then they have to be diverted to manual planting or destroyed.

MECHANICAL PLANTER PERFORMANCE

Valuable experience has been gained by all parties involved (nurseries, establishment teams and contractors) since mechanical planting was started over six years ago. In that time, over 2,500 ha have been planted mechanically in Coillte. Actual performance of the complete process has been evaluated using a number of surveys over the last number of years. These surveys included:

1. Satisfaction with plant quality (survey of contractors)

Two aspects of plant morphology are crucial for contractors – evenness of plant size and quality of the actual cell. An operator can adjust the machine settings on a daily basis for small or large plants but cannot cope with variability during the day. Initially contractors were not happy with the variability in height both within and between boxes of plants. This problem was overcome, however, by greater care in the sort/despatch from the nursery. The compactness of the cell (peat and roots) is also very important as plants will not slip down the planting tube of the planter if the root ball has fallen apart. Once correct sort/despatch procedures are in place in the nursery, this is not a problem.

2. Satisfaction with planter performance (survey of Establishment Team members)

The users of mechanical planting, when surveyed, were generally very happy with the operation. The main reason for this was that they had one point of contact (the contractor) for almost all of the establishment operations. It is the contractor who organises the delivery and on-site distribution of the plants, in addition to the cultivation, planting and spraying operations. All Establishment Team members said that they would use mechanical planting again.

3. Early performance of mechanically planted sites

Survival and early growth of mechanically planted areas were monitored using site surveys. Ten sites were assessed, six of which were planted by the EcoPlanter and three by a Bracke Planter. One site (Clondonnel) had both planters working on it. Results are presented in Figure 1.

Results were generally very good, with an average survival rate of over 90 percent after one year. After two years, survival dropped to below 80 percent on three of the ten sites. Two of these latter sites (Crutt and Rossmore) were unsuitable for mechanical planting as they were too wet and had not received any drainage at planting. On the third site, survival was poor because of weevil damage.

Early height growth and stocking levels were also assessed in the surveys. On average across all sites, trees put on height increment during the first growing season of 75% of their initial height. This is very encouraging and compares very favourably with the early height growth of transplants. Overall stocking rates at planting were excellent and averaged 2543 trees/ha for all sites. There were slight differences between the two machines with the average stocking for the Bracke (2607 trees/ha) slightly greater than that for the EcoPlanter (2479 trees/ha). The range of planting densities across all sites was similar for both machines (2356 to 2745 trees/ha) and plant spacing was generally excellent and usually in lines.

ADVANTAGES AND DISADVANTAGES OF MECHANISED PLANTING WITH CONTAINER STOCK

Advantages

Based on our experiences so far, some of the advantages of using container stock and mechanical planting are:

Planting season. The use of container stock means that the planting season is extended

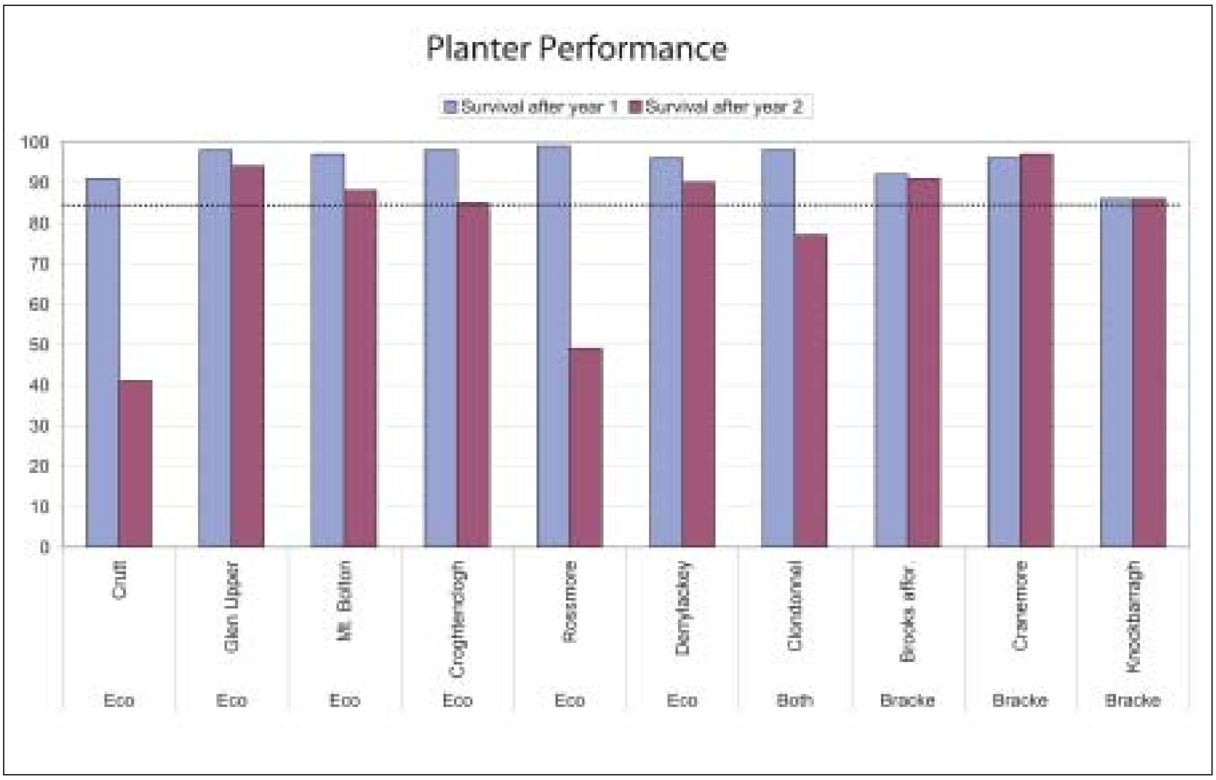


Figure 1. Survival of mechanically planted trees on ten sites after one and two growing seasons.

compared to bare-root stock. This has huge advantages for autumn and summer planting times when no bare-root planting can be carried out. We have had good experiences with Bracke planting even over a twelve month period.

Management. As mentioned earlier, using either planter makes the job of managing the establishment process much easier. One contractor dealing with most of the site operations reduces workloads on the site supervisor.

Plantation performance. Plantations established using mechanised planting of container stock have performed very well in surveys of establishment success.

Weevil control. Using the Bracke or EcoPlanter to carry out weevil control at the time of planting is very effective and concentrates the insecticide where it is required. It also reduces the operator's contact with treated plants.

Species change. The shorter growing cycle used for container stock means that this growing method is more adaptable to changes in species requirements than that used for transplant stock.

Cultivation area. With either of the existing planting machines, the total area cultivated is less than that cultivated under more usual systems. This has major advantages in, for example, planting riparian or native woodland.

Disadvantages

Plant size and cost. Container plants used in mechanical planting are smaller (height and root collar diameter) than transplant stock. As such, they can be very vulnerable to weevil or mammal attack unless protected well. The cost of container stock is high relative to transplant stock and this is a deterrent to their being used more.

Novelty. Mechanical planters are relatively new to Coillte and it sometimes can be difficult to persuade some establishment foresters to use them. Some remain loyal to existing cultivation and planting contractors and do not wish to change.

Site suitability. Both the EcoPlanter and the Bracke Planter are limited to certain site types. This can prove to be a difficulty in terms of putting a programme of work together for a particular machine.

Availability. Most of the existing fleet of mechanised planters are in the south and east. There is little scope for their being used in other parts of the country, as contractors are often not willing to travel and large programmes are not available in other areas.

Training. Most of the contractors that are interested in mechanical planting come from a site cultivation background. As such, they are used to dealing with machines and not with plants. They need to be trained in the handling and care of plants.

FUTURE DEVELOPMENTS

Research is quite active in the area of mechanical planting and in other related areas that impact on it. On the equipment side, Bracke Forest have recently developed a larger carousel for the Bracke Planter. It is designed to triple the existing carousel capacity to over 200 plants. This will result in the operator having to leave the cab a lot less to load the carousel with plants. It is hoped to test the new carousel in Ireland in the spring of 2006.

Another machine development that could affect the role of planting machines is that of brash bundling. This equipment gathers brash after clearfelling, bundles it and the bundle is later chipped for fuel. This equipment would leave the site relatively free of brash, thus making the planting operation much easier. A brash bundler has already been demonstrated in this country and further evaluation will take place this year.

Two recent developments in the area of pine weevil control have already been tested using mechanical planters. Some Bracke Planters in Scotland have been fitted with applicators which apply a granular insecticide to the planting hole at the time of planting. This systemic insecticide is taken up by the growing plant. The system has not been tested in this country yet.

Another development in the area of protecting plants against weevil is the WeeNet. This plastic sleeve, developed by Alba Trees in Scotland, is slipped over the container plant in the nursery just prior to despatch. It protects the tree by preventing access by the weevil to the main stem. It has been tested with mixed success in this country in the last year and can be used for manual and mechanical planting.

CONCLUSIONS

Mechanical planters are now an accepted tool in forest establishment in Coillte, with over 2,500 ha planted in this way already.

Within Coillte, we must ensure that planting programmes are in place to ensure work for contractors who have invested in mechanical planters.

Although the operation reduces overhead costs, we need to strive to reduce the actual cost of producing container plants and look for further efficiencies in the machine side of the operation.

We need to continuously monitor plantations, established using mechanically planted container stock, to assess survival and early growth.

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Minister John Browne, TD, and participants at the Plant Quality conference, September 2005.