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

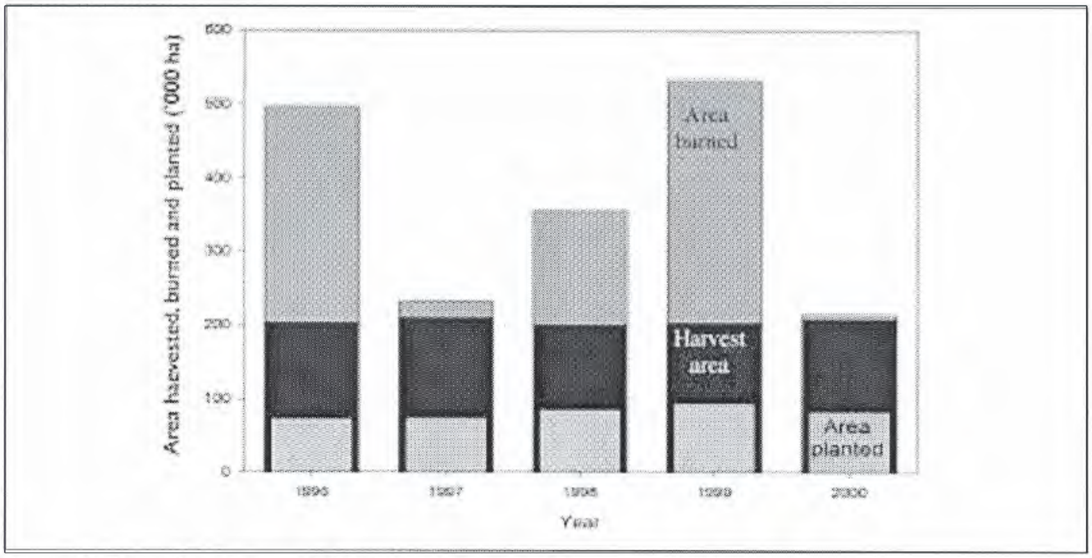

Figure 1. Forest disturbance and planting statistics for Ontario, Canada.

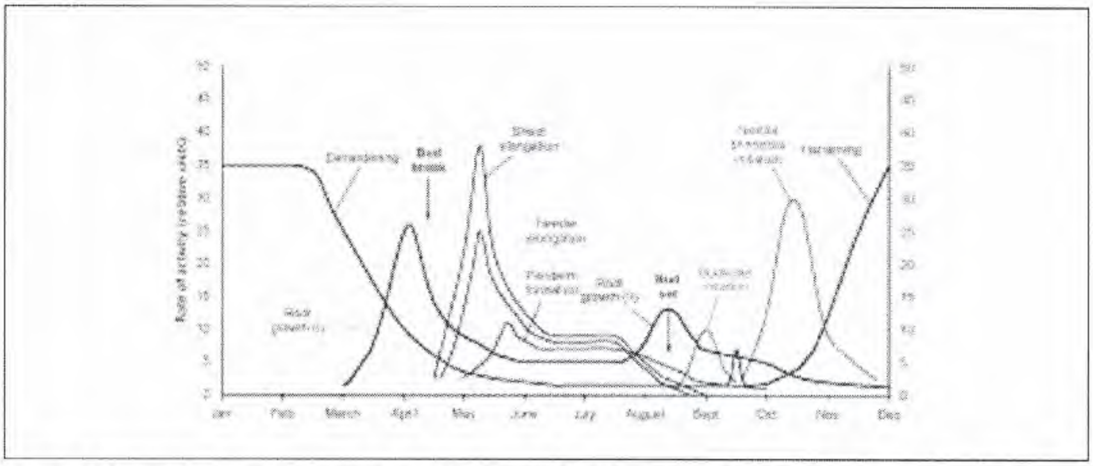

Figure 2. A typical annual sequence of growth rate and physiological condition that occurs to seedlings in a nursery. The rate or intensity of growth or physiological condition is shown by the height of the line on the y-axis.

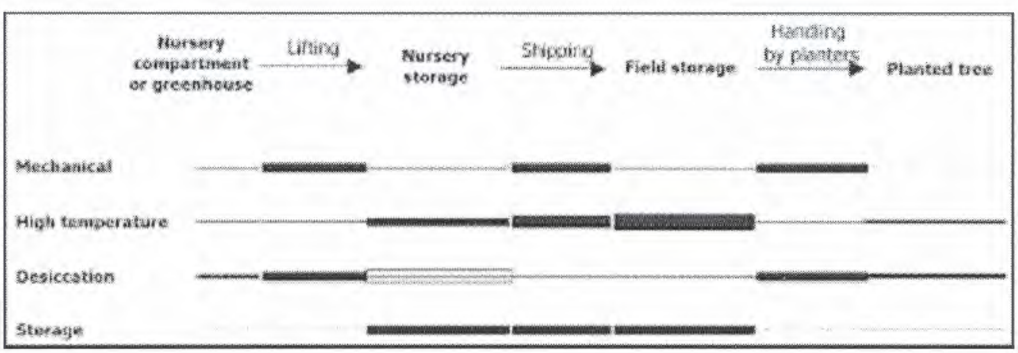

Figure 3. Risk diagram of handling stresses affecting tree seedlings. Thicker lines mean greater risk of damage from a stress during the time indicated.

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 scaled 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.

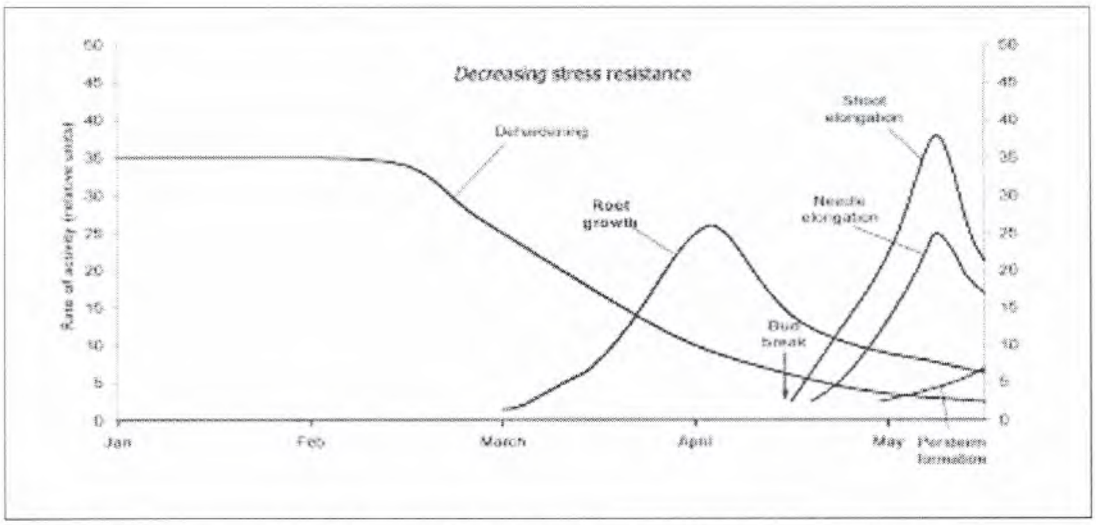

Figure 4. Spring sequence of growth rate and physiological condition that occurs to seedlings in a nursery.

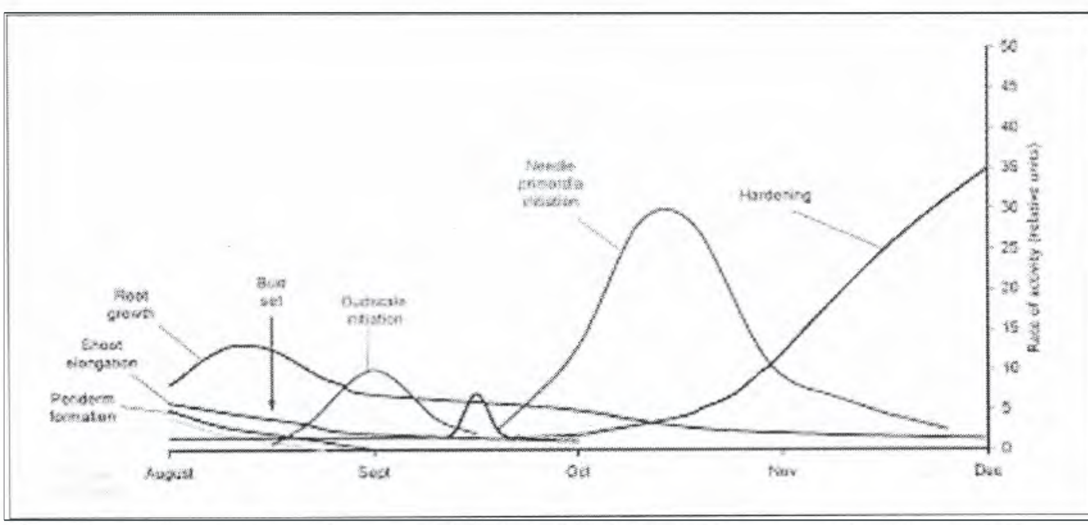

Figure 5. Fall sequence of growth rate and physiological condition that occurs to seedlings in a nursery.

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 dine.

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

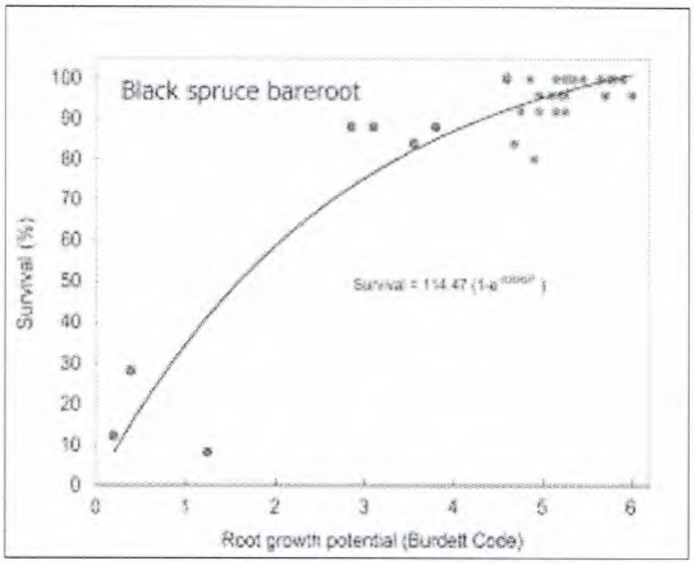

Figure 6. Relationship between plantation survival and root growth potential of bare-root black spruce. The Burdett Code of root growth potential is: 0 = no new roots, 1 = some new roots, none 1 cm in length, and Code values 2, 3, 4, 5, and 6 are respectively 1-3 new roots 1 cm or more in length, 4-10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

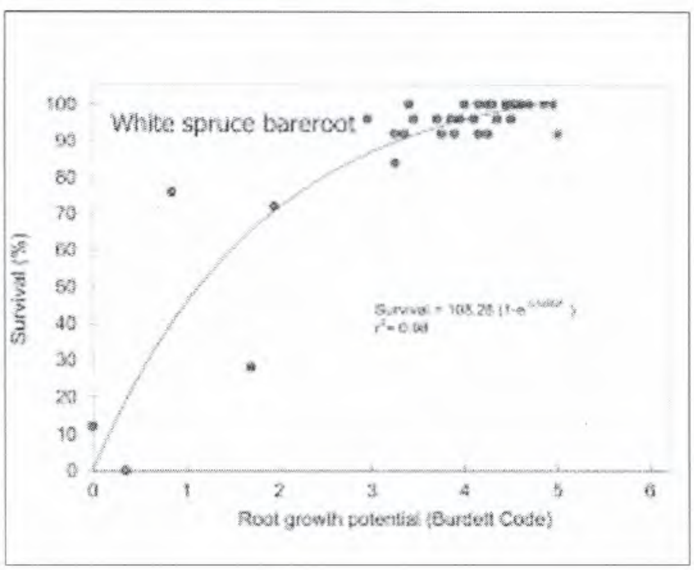

Figure 7. Relationship between plantation survival and root growth potential of bare-root white spruce.

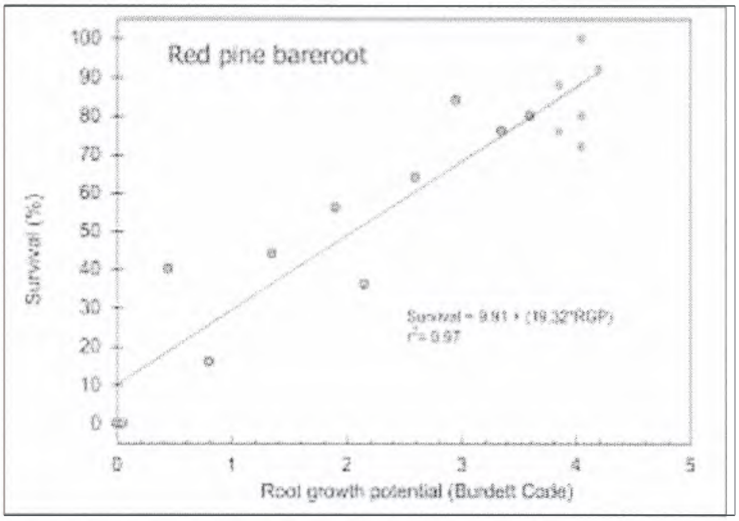

Figure 8. Relationship between plantation survival and root growth potential of bare-root red pine.

(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.