SITE-SPECIFIC RELATIONSHIPS OF ROOT GROWTH POTENTIAL TO OUTPLANTING PERFORMANCE OF COASTAL DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* [MIRC.] FRANCO) UNDER CONTROLLED IRRIGATED FIELD CONDITIONS

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ABSTRACT

Root growth potential (RGP) of a range of Coastal Douglas-fir *Pseudotsuga menziesii* [Mirb.] Franco) stocktypes and lift dates was examined as a predictor of site-specific outplanting performance under farm-field conditions of three experimentally controlled irrigation regimes. RGP test results were highly variable. The irrigation regimes resulted in site-specific mortality, growth, and form. RGP was weakly related to mortality and growth, but only for the very driest irrigation regime. For predicting survival or growth of Coastal Douglas-fir under different experimental field moisture regimes, the RGP test is of little use. These results raise questions about the use operational utility of RGP where handling, planting, and climate may further confound the relationship between RGP and plantation survival and performance.

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INTRODUCTION

Plantation performance depends on the use of high quality seedlings. Inspecting seedlings before planting to predict plantation performance is a common practise (Duryea 1985). Stock quality grading has traditionally been based on morphological attributes — primarily seedling size. Grading by seedling height and caliper has proved to be of limited value. More recently, other morphological, anatomical, and physiological criteria have been tested as ways of grading stock (Burdett 1983; Duryea 1985).

For physiological stock grading, measuring root growth potential (RGP; see Ritchie and Dunlap [1980] and Sutton [1990] for synonymy) is considered to be a useful indicator of seedling quality (Burdett 1987). The RGP of a seedling reflects the seedling's ability to initiate and elongate roots when it is placed into an environment favorable for root growth (Ritchie 1985). RGP has been considered to be positively correlated to seedling survival and growth (Burdett, *et al*. 1983; McCleary and Duryea 1987).

Stock quality has been defined as ''fitness for a purpose'' (Sutton 1980). To be a useful stock quality assessment technique, RGP must therefore be capable of being interpreted in a site-specific manner. Relating physiological attributes to the conditions of the intended planting site and environment would aid allocating stock to plantations. As intuitively appealing as this hypothesis is (Burdett 1987), use of site-specific interpretations of RGP have not been tested under well-defined field environments. That is, stock with high RGP is expected to survive and perform better over a wider range of sites than is stock with low RGP. Low RGP stock is assumed to be more prone to damage under harsh environmental conditions than is higher RGP stock. In this paper we examine the site-specific applicability of RGP tests in predicting survival and performance of Douglas-fir seedlings in coastal British Columbia.

MATERIALS AND METHODS

Seedlings and Planting

Three stocktypes (container, bareroot, and transplant) of a single seedlot of coastal Douglas-fir were grown at a single nursery on southern Vancouver Island. The seedlings were taken from a larger operational crop. The seedlings were lifted at three dates during the winter of 1985–86 (Table 1). All stock was hand lifted, operationally culled, packaged and cool-stored (+2 °C) until planting in late May 1986.

TABLE 1. Stocktypes and lift dates

Lift date	**Stocktypes**		
	Container	**Transplant**	**Bareroot**
December 15	1	4	F
January 15	2	NA	5
February 15	3	NA	NA

F - *Botrytis* infestation: not planted.
NA - No stock available.

Seedlings were lifted outside the normal operational lifting window in order to include the largest variation in potential stock quality, and thus RGP values. Commercially, the December lift date would have been preferred because the stock would have been expected to be dormant. This sampling included seedlings in various dormancy states to produce a wide range of RGP (Ritchie and Dunlap 1980).

All seedlings were planted at a 0.5 m spacing in one day by four planters. Planters were randomly assigned to rows to minimize confounding of planter and stocktype effects. The different stocktype/lift date combinations were randomly planted throughout the planting period of the experiment to minimize time-related effects. As the field had been plowed clear just before planting, there were no physical impediments to planting.

Field Conditions

All seedlings were planted in an abandoned farm field at Harmac (49° 10′ × 123° 50′), south of Nanaimo on Vancouver Island, British Columbia. Establishing the experiment in a fenced farm field was preferable to establishing it in an operational plantation where browsing and site heterogeneity could confound results. A farm field environment also allowed for closer spacing during planting.

Three levels of moisture regime, (referred to as Dry, Fresh, and Moist sites) to approximate dry, moist, and wet forest ecosystems, were established by irrigation throughout the growing season according to the schedule in Table 2. The different soil depths intensified the irrigation effects. Each stocktype/lift date combination in an irrigated treatment was represented by five, 20-tree rows. The rows were randomly located in each irrigation treatment.

TABLE 2. Irrigation conditions and site conditions

Site name	Irrigation schedule	Average soil depth (cm)
Dry	No irrigation	55
Fresh	Every two weeks	80
Moist	Every week	110

The irrigation regime, modeled after Blake, *et al*. (1979), was carried out for two years. In each irrigation regime, soil moisture at three depths (10, 20, and 30 cm) was measured weekly with gypsum blocks. Moisture block readings were calibrated against gravimetric sampling methods to determine soil moisture. Soil temperatures were measured weekly using thermocouples buried at depths of 10, 20, and 30 cm. Gypsum blocks and thermocouples were located at three random locations in each irrigation treatment.

The field was cleared by plowing at the beginning of the experiment, but no vegetation control was conducted. Vegetation growth was monitored by 1-m^2 clip plots which were harvested at the end of August of the second year. Five clip plots per irrigation regime were randomly sampled. All vegetation from the clip plots (grasses, forbs, and shrubs) were oven-dried at 100°C to a constant weight.

Planting Conditions

The climate and site conditions were ideal for transplanting and establishment. The weather during planting was cool and rainy, with low wind speeds. These conditions persisted for several days after planting. Soil moisture and temperature conditions on all irrigation treatments remained similar for the first six weeks after planting (Figure 1).

Seedling Measurements

Seedlings were monitored for two growing seasons. Survival was assessed two weeks after planting and in the spring and fall each year for two years. Seedling height and diameter were measured at the end of each growing season. Form and damage variables were also noted at the end of the growing season. Relative growth was calculated as the percentage of total two-year height increment to the initial height at planting.

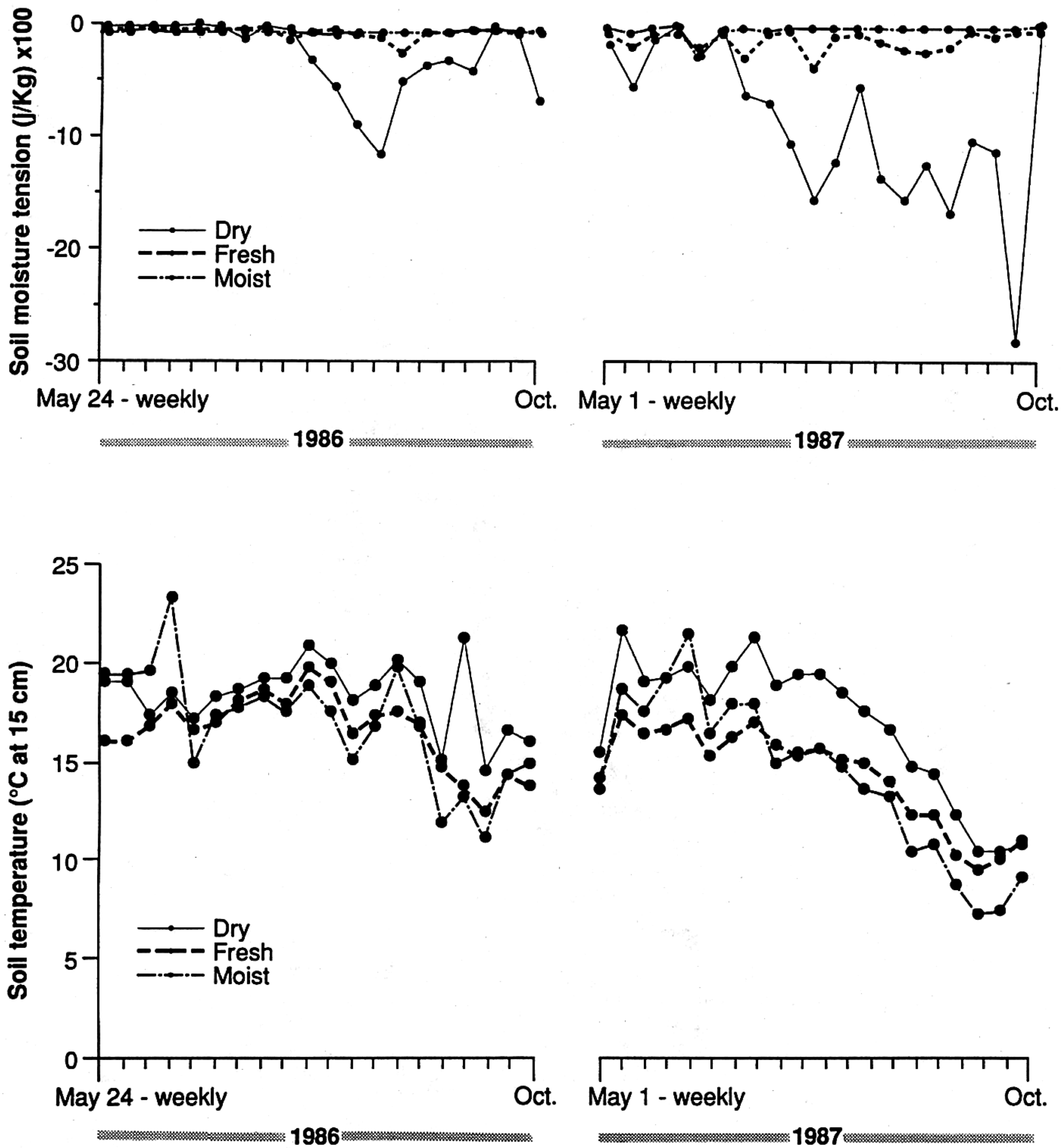

FIGURE 1. Average soil (a) moisture tension and (b) temperature. Average moisture tensions based on three gypsum blocks per irrigation regime. Gypsum blocks buried at 10, 20, and 30 cm. Extreme soil moisture tensions in the fall of the second year reflect the gypsum blocks losing contact with the soil during the drought. Average temperatures based on three thermocouples per irrigation regime buried at 10, 20, and 30 cm. Soil moisture and temperature measurements were not conducted over the winter months.

Root Growth Potential Tests

Root growth potential tests were conducted at lifting and at planting, under the same conditions as described by Binder, *et al.* (1990). Testing was conducted before and after storage to determine whether RGP degradation had occurred during storage. The RGP results are expressed as the number of white roots longer than 10 mm.

Data Analysis

Box plots were used to report the results as in Binder, *et al.* (1990). Notched box plots represent the central tendency, spread, and range of a body of data (McGill *et al.* 1978; Titus 1987; Bergerud 1988). The insert in Figure 2 details the graphic convention used. As notches represent 95% confidence intervals about the median, those boxes whose notches do not overlap can be regarded as statistically different. Box plots illustrate the partitioning performed by ANOVA, and are analytically appropriate where data are highly variable and depart from normality. They are particularly useful in studies that examine variability in addition to central tendency.

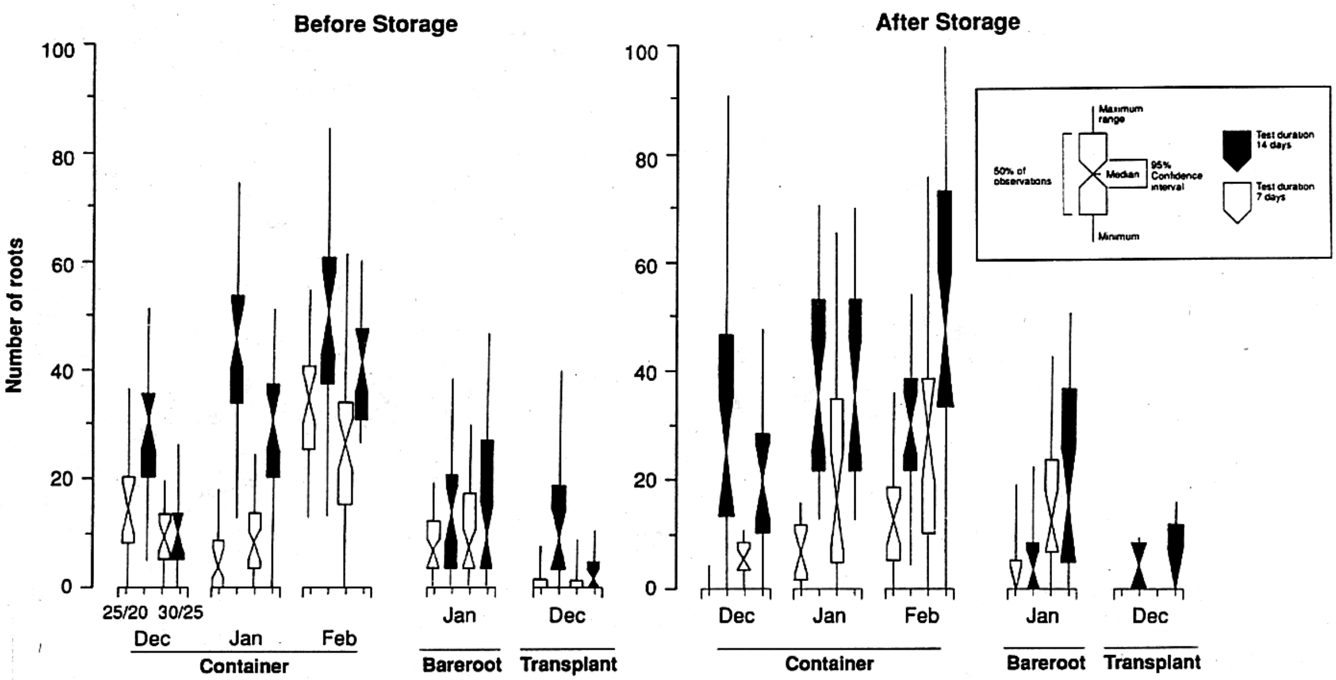

FIGURE 2. Root growth potential (RGP) test results. Notched box plots of stocktype/lift date combinations. RGP tests performed at: (a) before storage at lifting; and (b) after storage immediately before planting. Unshaded box plots: 7-day duration tests. Filled box plots: 14-day duration tests. The inset illustrates the graphic convention for the various parts of a hypothetical box plot. If notches overlap, the test can be regarded as not statistically different at a $p \leq 5\%$. Tests with no box illustrated had no root growth.

RESULTS

RGP Tests

The largest source of RGP variation was within-test (Figure 2). At lifting, more roots were produced under cooler test temperatures (25/20°C). The largest variability of RGP also occurred under those temperatures. For the container-grown stock this situation was reversed after storage. More roots and higher within-test variability occurred for that stock under the warmer temperature conditions. RGP variability increased during cold storage, but did not decline.

On the basis of the optimal root production test (25/20°C 14-day test; see also Binder, *et al.* 1990), container-grown stock had significantly greater RGP than did either the bareroot or transplant stock. The transplant stock had the lowest RGP and the least variation. This ranking of stocktypes was the same before and after storage. The site-specific hypothesis would therefore predict that the container stocktype would survive and perform better than the other stocktype /lift date combinations.

Field Conditions

Irrigation treatments altered the soil moisture, soil temperature, and vegetation coverage over the two years of the experiment. The unirrigated DRY site soil moisture exceeded -1000 J/kg (Figure 1), the FRESH site reached soil moisture tensions of 100 J/kg, and the MOIST site remained at or near field capacity. In both years, there were severe late-August soil moisture deficits on the unirrigated treatment.

Over the growing season, the soil temperatures of the DRY regime averaged 2°C warmer at 15 cm depth than the FRESH or MOIST irrigation treatments (Figure 1). The drought in the second year was associated with lower soil temperatures than the drought in the establishment year, possibly reflecting the establishment of vegetation on the treatments.

The most striking effect of irrigation was on the vegetation. As a result of irrigation, the herbs and shrubs grew rapidly on the FRESH and MOIST sites. By the end of the establishment year, three times as much herb and shrub biomass was produced on the MOIST site as the DRY site (Figure 3). The DRY site had only a low coverage and biomass of grasses and forbs.

At the end of the second year, the vegetation in the FRESH and MOIST sites was over 1.5 m tall.

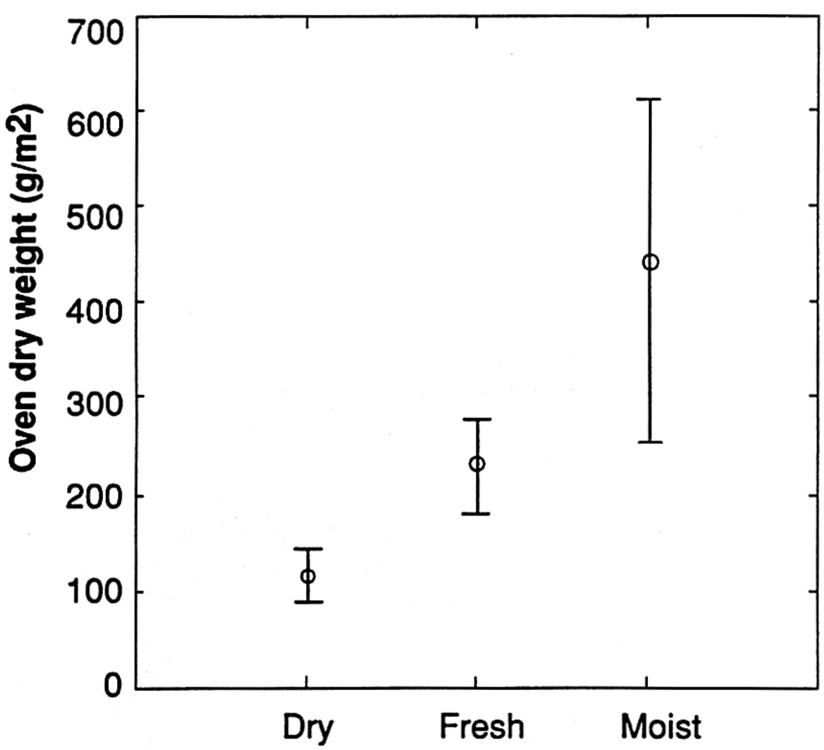

FIGURE 3. Second growing season herb and shrub biomass. Means and standard deviation of aerial biomass based on five 1-m^2 clip plots per irrigation regime after the second growing season (1987). Clip plots include grasses, forbs, and shrubs. Samples dried to constant mass before weighing.

Mortality

Seedling mortality occurred largely in the establishment year (Figure 4) and was evident within a few weeks of planting. After three weeks, the transplant and bareroot stock had barely flushed and many needles, particularly on the lower stem, were necrotic or had fallen from the seedlings. By contrast, many of the container stock had flushed and retained needles. All dead trees were excavated and examined for injury or planting errors, but death could not be assigned to these causes. By elimination, stock quality was implicated as the cause of mortality. Many of the trees that survived establishment but died in the second year had exhibited very reduced vigor and form defects in the first year.

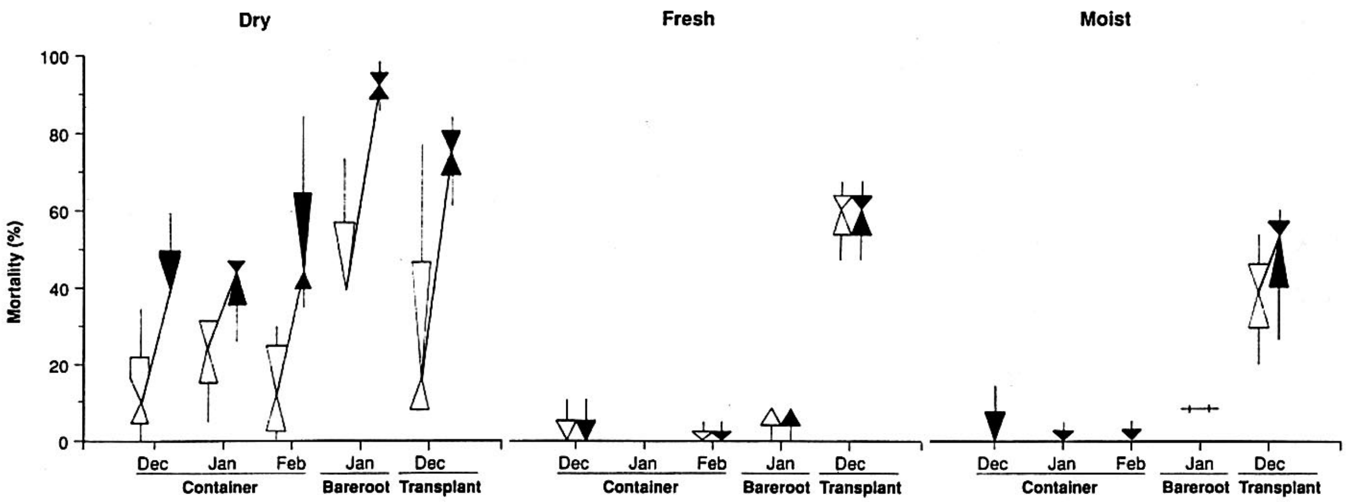

FIGURE 4. Cumulative mortality. Mortality based on 20-tree row occurrence. Unshaded box plots are the first year mortality; shaded are the second year. Lines connecting box plot medians connect establishment to second-year mortality for individual stocktype/lift date combinations.

The DRY site had the highest mortality (15−40% mortality in the first season) over all stocktypes and lift dates (Figure 4). The mortality increased significantly in the second year to at least 40% mortality on the DRY site. The seedlings dying in the second year were of poor vigor at the end of the first year. The mortality on the FRESH and MOIST sites was generally less than 10%. No within-irrigation treatment patterns of mortality were apparent.

The stocktype with the lowest RGP, the transplanted stock, also had the poorest survival in all irrigation regimes — greater than 40% mortality (Figure 5). RGP correctly identified the transplant stock as problematic. None of the stocktype/lift date combinations had acceptable survivals on the DRY site (i.e., survival less than 80%).

Only the bareroot and the container stock had acceptable mortality on the FRESH and MOIST sites. In the bareroot stocktype, the low mortality is at variance with the low RGP test results which otherwise suggested poor quality stock. Perhaps the RGP test conditions for this stocktype were not appropriate for predicting the field performance (Binder, *et al.* 1990).Only the mortality on the DRY site suggested that there was the expected site-specific relationship between mortality and RGP: low RGP stock performed the poorest on the driest site. The magnitude of the variability for both RGP and mortality obviates fitting a curve to this data.

If other test conditions had been used, the nature of the relationship between mortality and RGP would have been different. For example, the post-storage 7-day 25 /20°C test (Figure 2) would have indicated that the December-lifted container and transplant stock could be a problem. Alternatively, the December-lifted stock could have been the most dormant and thus least likely to respond to testing. The low mortality indicates that the December-lifted container stock had few problems. This variation in RGP interpretation emphasizes the need for specifying the test conditions (Sutton 1990) of an RGP test and the history of the stock tested.

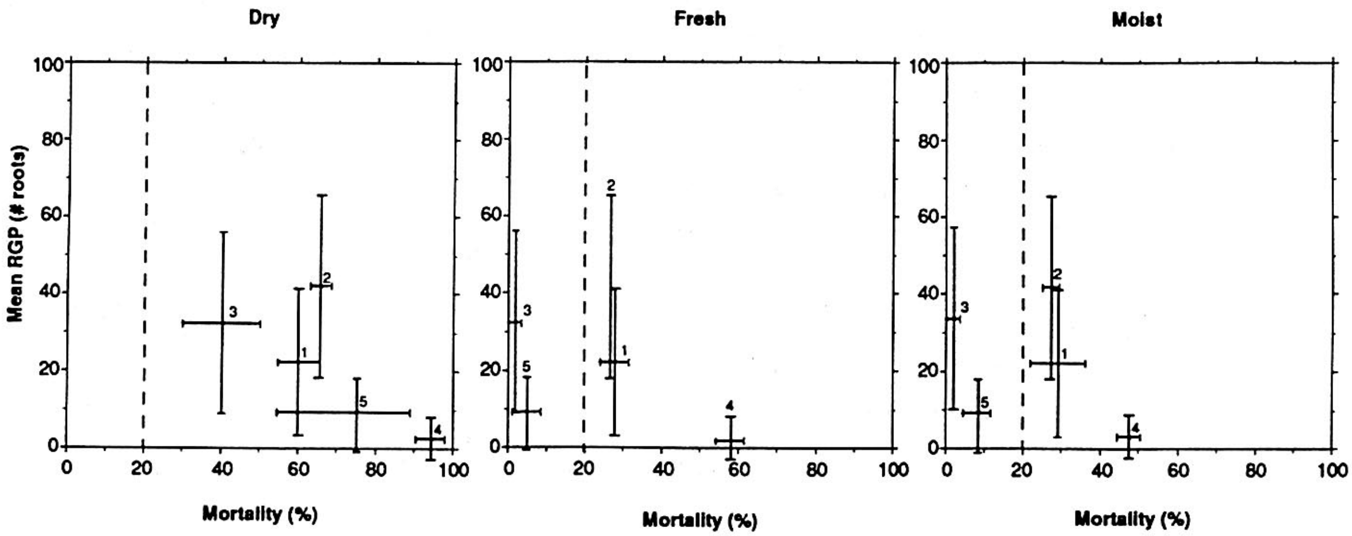

FIGURE 5. RGP relation to mortality. Mortality based on row occurrence. RGP based on 25/20°C 14-day post-storage test. Means and standard deviations given for **both** mortality and RGP. Vertical line at 20% mortality separates acceptable from unacceptable mortality. Numbers correspond to those in Table 1 for stocktype/lift date combinations.

Growth

The amount of shoot growth was directly related to irrigation (Figure 6). Except for stocktypes, there was no discernible within-irrigation regime pattern of growth. Except for trees on the DRY site, the growth rate in the second year increased dramatically compared to the establishment year. The trees on the DRY irrigation regime grew only 10 cm in two years. The trees on the MOIST site showed the least growth in the first season ("planting shock") and had the highest growth rates — 50 cm in two years. The superior performance of the trees on the MOIST site is at variance with the extreme competition created by the dense grass sward and shrubs.

On the DRY site, RGP and relative growth had a very weak inverse relationship (Figure 7). This may be due to two confounding factors: leader dieback and lammas growth. A high incidence of terminal bud death and leader dieback occurred during the establishment year in the bareroot and, to a lesser extent in the transplant stock (Figure 8). The high incidence of lammas growth on the MOIST and FRESH sites further accentuated the appearance of an inverse relationship to RGP (Figure 9).

The acceptable survival of the bareroot stock, but the high incidence of leader dieback and bud death, emphasizes the need to examine more than an RGP test when making stock quality interpretations. In an operational plantation, loss of an annual increment early in plantation establishment could mean the difference between free-growing trees or expensive brushing and site rehabilitation.

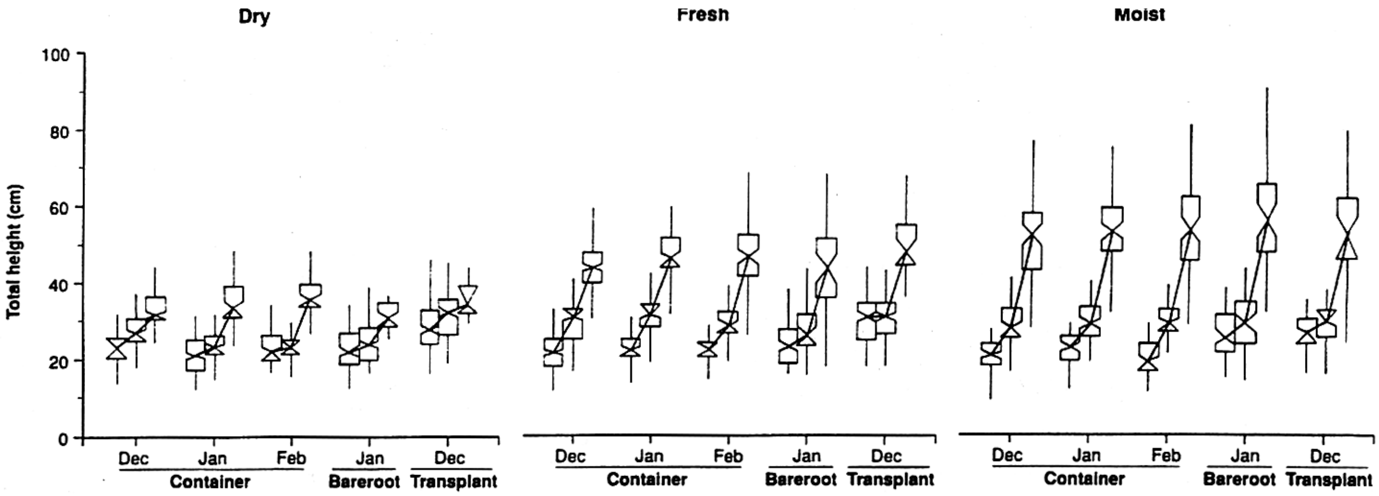

FIGURE 6. Cumulative height growth. Box plots of cumulative height growth for different stocktype/lift dates on the three different irrigation regimes. Box plots are, from left to right: height at planting; height after establishment year; and height after two years. Lines connecting box plot medians are for subsequent growth for individual stocktype/lift date combinations. The steeper the slope of the line connecting the box plots, the greater the growth rate. Boxes pool all seedlings in the stocktype/lift date combinations because of severe stocktype-dependent mortality in the DRY irrigation regime (Figure 4).

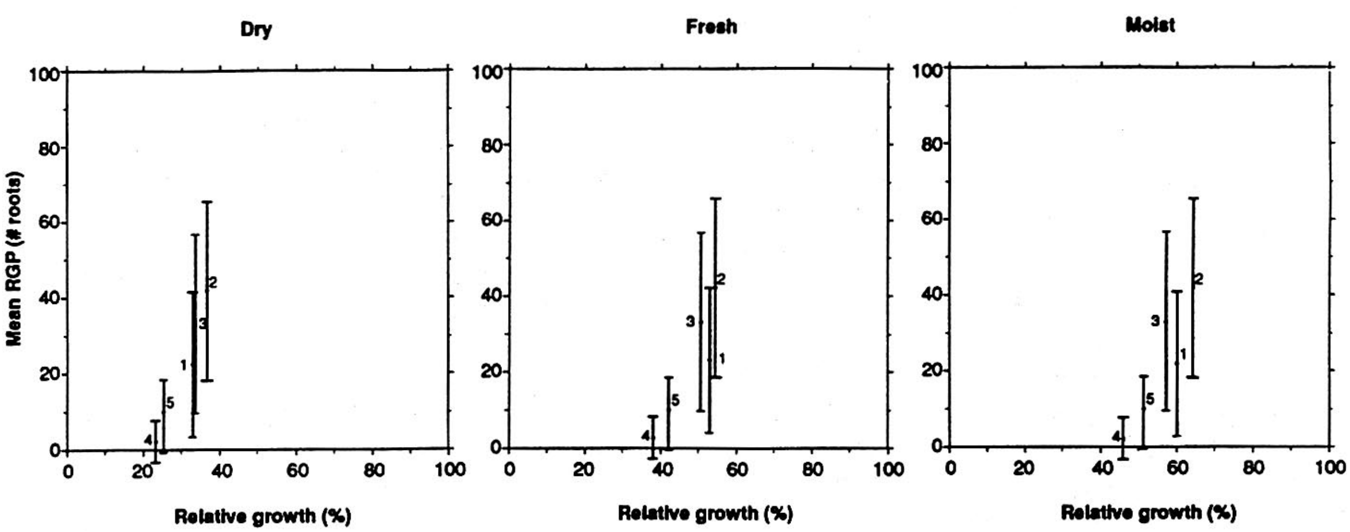

FIGURE 7. RGP relation to relative growth. Relative growth expressed as the percentage of two-year increment to initial height at planting. Relative growth pooled over all seedlings for a stocktype/lift date combination per irrigation regime. RGP based on 25/20°C 14-day test post-storage test. Means and standard deviations given for RGP.

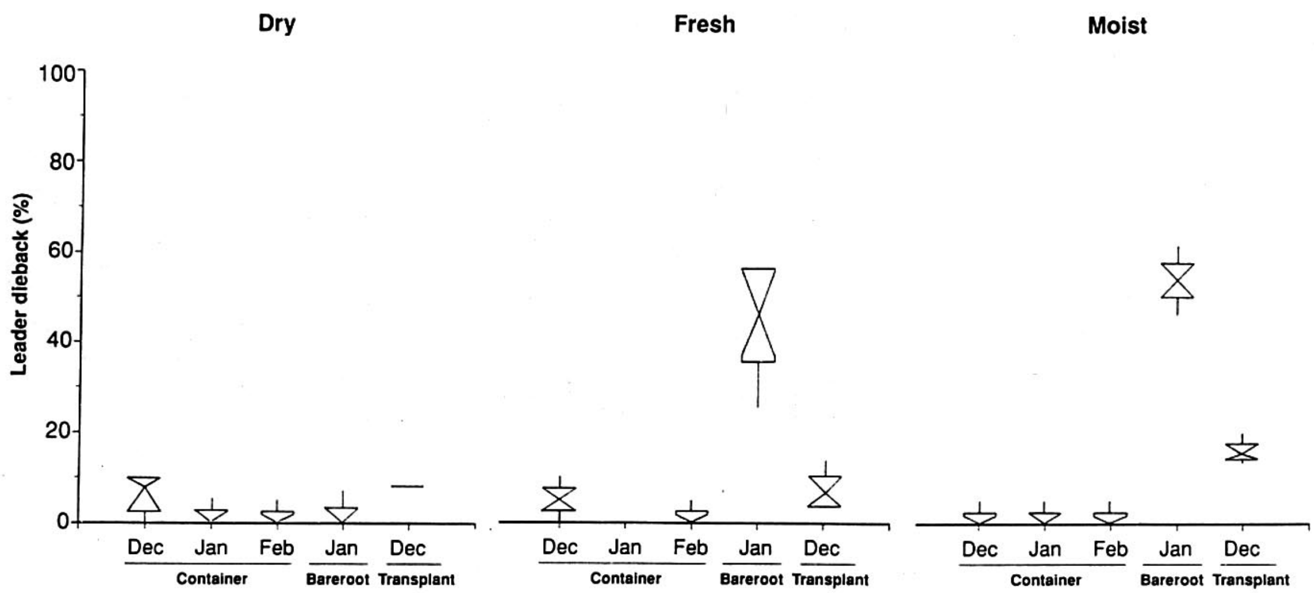

FIGURE 8. Leader dieback incidence. Includes leader dieback and death of terminal buds. Incidence is based on row occurrence.

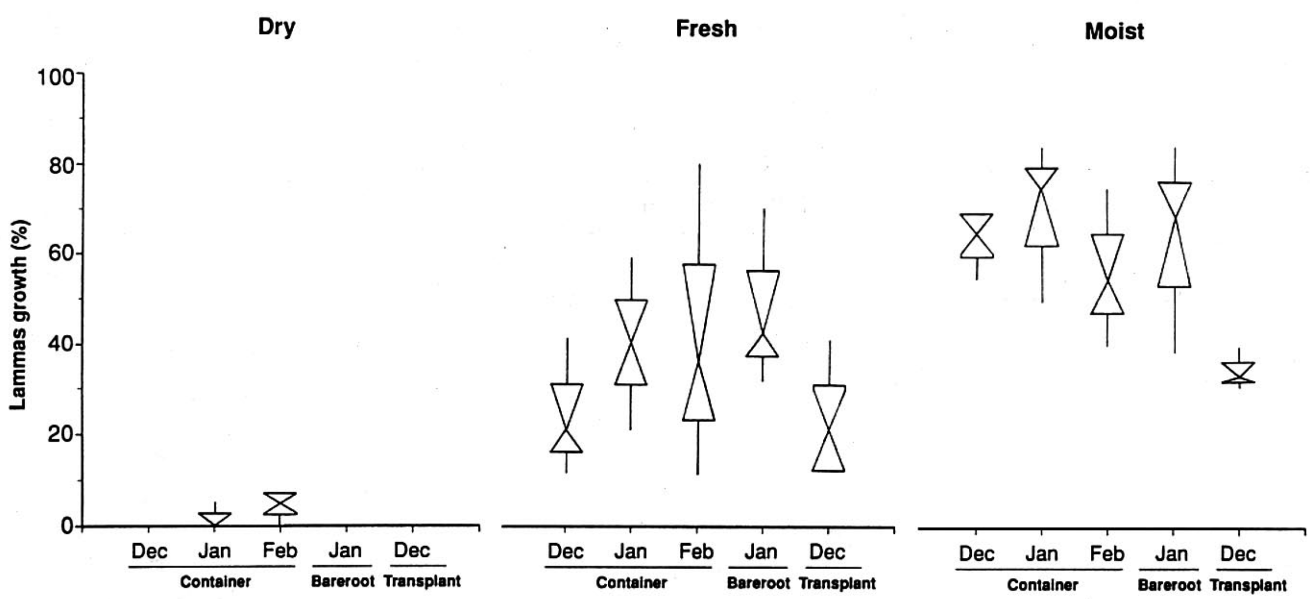

FIGURE 9. Lammas growth incidence. Lammas growth based on the row occurrence at the end of the second growing season.

DISCUSSION

Despite the large site-specific differences in survival and growth evident in this study, RGP test results were so variable that it was not an adequate predictor of tree mortality or height growth. The utility of RGP under more stringent operational conditions (Edgren 1984) would still likely be poor, but it must be tested (Puttonen 1989). The strongest relationship between RGP and mortality and growth appeared to exist on the driest site. If still drier irrigation regimes had been possible in this experiment, the threshold suggested by Simpson, *et al*. (1989) may have been realized. This agrees with van den Driessche (1983) and corroborates the basis of the site-specific hypothesis that poor stock is always poor stock as its performance will not be realized to the same extent under all sites conditions.

Our results contradict those generally reported by other researchers (Burdett, *et al*. 1983; Ritchie 1985) which may be a result of the limited range in the RGP of the stock tested (Burdett 1987). Furthermore, the extremely favorable or unfavorable conditions experienced (Burdett 1987) might have obscured the RGP correlation to field performance.

The variability in RGP test results is of the same magnitude as reported by Binder, *et al*. (1990). Others also have commented on the high variability of RGP (Stone 1955; Stone, *et al*. 1962; Abod, *et al*. 1979; Stupendick and Shepherd 1979; Rietveld and Tinus 1987). The variability found in this study is of such a range that we question the practical significance of the statistical fit of RGP test results to outplanting mortality or growth where the results are unaccompanied by standard errors (see Burdett 1979; McCleary and Duryea 1987). Indeed, because of this variability, we wonder if there is any point in correlating any other physiological tests against RGP.

An RGP test does have a place in the grading of stock, but it should not be elevated to the status of a regulation, subordinating other grading methods. It may only provide special-purpose indications of stock quality. The high, within-test variation makes strict, probabilistic interpretations of RGP inappropriate for grading because of the test variability. It is worth remembering that RGP was conceived as a simple pot trial of bareroot stock (Stone 1955).

We do not think that any single method of grading nursery stock should be used alone in examining physiological conditions. Although it would be ideal to have a technique that is unambiguous and requires no further explanation, the nature of biological systems does not allow this, and RGP certainly does not satisfy this methodological ideal. To say that stock is of poor quality based on indirect or circumstantial evidence is not enough. Reasons must be given to substantiate these claims of poor quality. It is not that the stock is poor because it performed poorly on a test, rather, the stock performed poorly on a test because of some particular cultural, storage or handling conditions that might have caused or contributed to a degradation in stock quality. RGP test results alone are not sufficient indication of stock quality, they must be substantiated by other evidence.

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