Root Growth Potential: Facts, Myths, Value?[1]

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Abstract.-- Currently the Root Growth Potential (RGP) test enjoys a reputation as a general predictor of outplanting survival and growth. This study examines the accuracy, precision and repeatability of RGP. We conclude that the present use of RGP is neith9r highly accurate, precise, or repeatable: within-test variation is highly variable; different test environments and durations give different results; mean batch RGP values from operational RGP tests do not display strong relations to outplanting mortality or growth. We conclude that KGP has value as part of a stock evaluation program but it must not be the sole arbiter. Any interpretation of KGP test results for predicting outplanting performance must consider other information on stock condition, history, and site conditions.

INTRODUCTION

Root growth potential (RGP) has been portrayed by research as a "thermometer" of seedling quality (Ritchie 1985) The operational use is being increasingly advocated and applied (Anon. 1988).

Recent reviews (Burdett 1987; Sutton 1988) have focused on the lack of an understanding of the physiological basis for RGP. Derived stock quality interpretations are ambiguous. We take the position that this ambiguous interpretation of RGP is due to a failure to: recognize latent assumptions; unrealistic expectations; failure to specify purpose; and lack of methodological understanding of RGP. Here we expand on this position examining these previously ignored issues. We propose revised interpretations of RGP for operational purposes that are consistent with the test methodology.

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HISTORY AND ASSUMPTIONS OF RGP USE

Detailed reviews of the development and use of RGP have been published (Ritchie and Dunlap 1980; Ritchie 1985; Burdett 1987). It is important to distinguish the purpose, method, and interpretation of RGP. RGP testing was developed in response to poor field performance of conifer seedlings as a means of predicting operational outplanting performance (Stone 1955). In spite of numerous predictive claims made about RGP, the test is only a limited potting trial. RGP is simply a test of the potential to grow roots and says nothing about outplanting survival. Making an outplanting prediction is an interpretation of an RGP test.

Over the last 30 years RGP testing has been applied to virtually all conifer species and stocktypes as well as some hardwood species (Ritchie 1985; Burdett-1987). In British Columbia and many other places, RGP tests bear little resemblance to the 30-day greenhouse test of Stone and Jenkinson (1971). Present tests are conducted under much shorter test durations, elevated temperatures, prolonged day lengths, and controlled environments in a variety of media (Thompson and Timmis 1978). RGP is reported to be influenced by a variety of cultural practises (Ritchie and Dunlap 1980). Stocktype (Burdett et al. 1983), genotype and provenance (Nambiar et **al.** 1982), and dormancy state (Johnson-Flanagan and Owens 1985) have also been implicated.

Although the test conditions and materials have changed, the interpretations of the test have not. One has only to consider the changes in nursery culture and silvicultural practice of the last 30 years to question whether the original interpretations of RGP tests remain realistic without modification.

The operational appeal of RGP as a stock quality grading tool is based on the reported strong relation with outplanting performance (Fig. 1). The apparent simplicity and speed of the test (Day 1982) further enhances its attraction for operations.

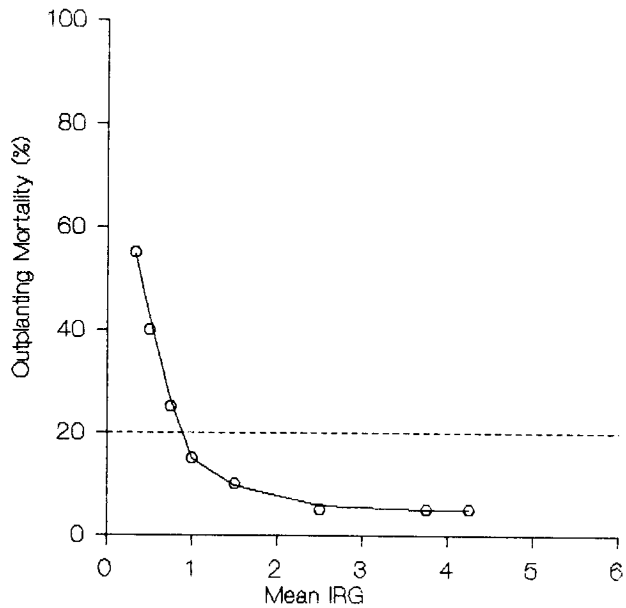

Figure 1.-- Relation between IRG and outplanting survival for bare-root lodgepole pine (after Burdett 1979, Figure 3). The horizontal line indicates an unacceptable mortality of 20%.

The fundamental assumption of RGP is quite reasonable:

> Individual seedlings exhibiting the largest number of new roots in an RGP test would have been better able to set new roots, survive, and grow in a plantation.

This assumption has led to the operational definition of the RGP test as:

> The <u>number</u> of roots initiated in a given interval of <u>time</u> under a <u>favorable environment</u> that are greater than 1 cm.

Numerous ways have been devised to test, express and interpret RGP (Ritchie 1985; Burdett 1987; Rietveld and Tinus 1987; Burr et al. 1987) but the basic methodological issues of accuracy, precision, and repeatability have not been explicitly considered. Like any measurement technique, RGP must be demonstrated to be accurate, precise, and repeatable before confidence can be placed in derived interpretations.

Before transferring this research technology to operational applications these methodological issues of accuracy, precision, and repeatability must be addressed.

ACCURACY, PRECISION, AND REPEATABILITY

Accuracy and precision are rigorously defined statistical concepts (Sokal and Rohlf 1969). Repeatability is the user-related component of accuracy and precision (i.e. observer error). These concepts are as important to the practice of statistics and conduct of laboratory technique as they are to target shooting (Fig. 2).

The accuracy, precision, and repeatability of a method determines the suitability for a specific purpose. Obviously one would wish any measurement technique to have high accuracy, precision, and give similar results regardless of who applies the test. However, useful methods may have poor precision but be accurate and repeatable enough to perform the required job.

The questions we are asking in this paper are:

1. Is RGP an <u>accurate</u> predictor of seedling vigor? (Can RGP correctly predict seedling survival?)
2. Is RGP a <u>precise</u> measurement of seedling vigor? (Is the variability of RGP measurements low?)
3. Is RGP a <u>repeatable</u> measurement? (Will several observers report the same result?)

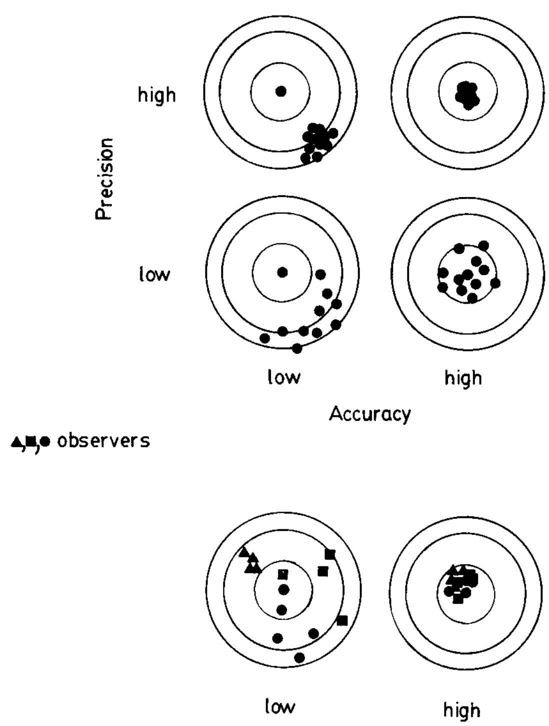

Figure 2.-- The sharpshooters analogy of accuracy, precision, and repeatability. The different shaped symbols represent different shooters.

TEST STABILITY

A common failure of RGP tests has been a lack of a standard test environment and duration. Thompson and Timmis (1978) reviewed the plethora of test environments used. New versions are published frequently (Burr et al. 1987; McCreary and Duryea 1987; Rietveld and Tinus 1987). Test environments have been described that are: sub-optimal, optimal, and too optimal. Among other factors, RGP has been shown to be influenced by test temperatures (Abod et al. 1979) and test media (Thompson and Timmis 1978). Without a clear understanding of the physiological basis of RGP, the choice of test environment and duration must be considered an arbitrary decision.

Figure 3 (Binder et al., in prep.) illustrates test variability in two seedlots of western hemlock. The within-test variation is high. There are large differences between test temperatures with an optimal temperature less than the 300 day/25onight'. Longer test durations produced more roots. "Optimal" temperatures varied among seedlots of other species tested. These results indicate that conditions of Burdett's "quick test" (Burdett 1979; 300 day/25onight for 7 days) may be too warm and short for coastal species.

The IRG differences observed under different test temperatures suggests that extrapolation from laboratory test conditions to highly variable and fluctuating, sub-optimal plantations conditions may not be reasonable. Indeed, the modest 5C0 diurnal variation encountered in laboratory growth chambers is physiologically trivial compared to the 3000 diurnal fluctuation seen in many operational plantations.

Others have commented on the Large within-test variability (Stone et al. 1962; Stupendick and Shepherd 1979; Abod et al. 1979; Rietveld and Tinus 1987) and have made qualifying remarks concerning the research interpretations drawn. Although this variation has been commented on, it has not usually been graphically portrayed (i.e. Burdett 1979; McCreary and Duryea 1987) contributing to the impression of strong relation to outplanting mortality and growth.

The reported wide range of test conditions suggests poor repeatability between different studies. The large within-test variation results and observations suggest that RGP test results have poor precision.

' Unless otherwise specified all RGP tests were performed at 25CO 16 hour day of 4U0 uEm^{-2}sec^{-}-provided by fluorescent and incandescent lamps. The 8-hour night temperature was 2000. Tests were run for 7 days. Relative humidity of the growth chambers was 75't±5%. Tests consisted of 16 seedlings potted four to a 6" pot of 3:1 peat vermiculite adjusted to pH 5.0 with dolomite lime.

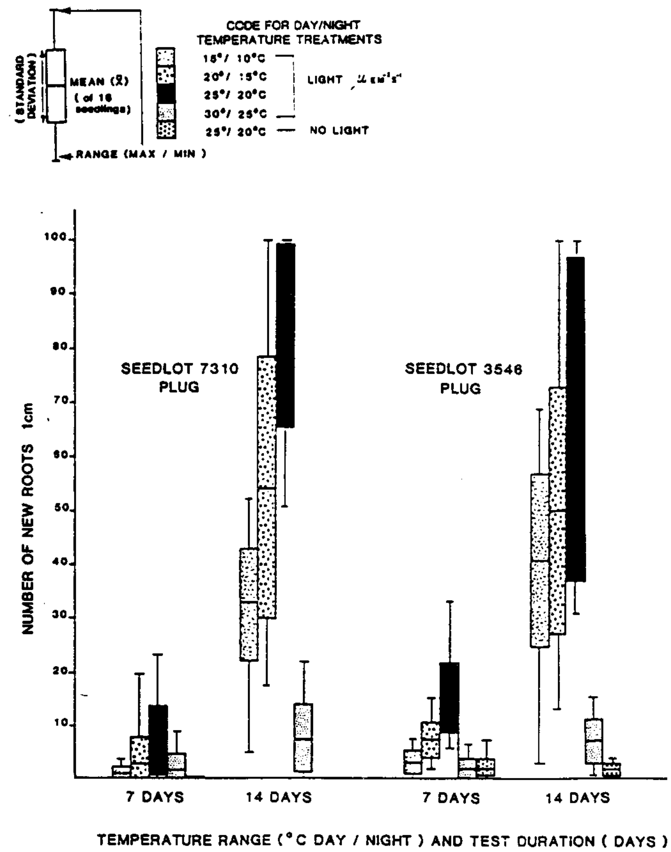

Figure 3.-- Comparison of the RGP for two seedlots of container-grown western hemlock tested under 5 test temperatures and two test durations (Binder et al., unpubl.).

NURSERY OUTPLANTING

Following Burdett et al. (1983) the British Columbia Ministry of Forests and Lands established an RGP monitoring program. Test temperatures and durations were standardized for all species (Binder, unpubl.) and nursery outplantings conducted at four nurseries. RGP tests were based on 16 seedlings. Nursery outplanting is based on plots of 50 seedlings. Twelve species and a wide diversity of stock types were examined.

The relation of IRG to nursery outplanting of 540 different batches is given in Figure 4. This figure represents 8,640 RGP tested seedlings and 27,000 seedlings in outplanting plots. No equation has been fitted through this point swarm as the large sample size makes it possible to claim statistical significance for any imaginable curve. Drawing such a line through the data gives credibility to a correlation that lacks general practical significance. The high within-test variation observed in Figure 3 also exists in this data. Including standard errors around the mean IRG values in Figure 4 would reinforce the impression of randomness.

The good news contained in Figure 4 is that only 12% of the seedlots tested had an unacceptable mortality of greater than 20%. The majority of mortality occurred within the first year of the outplanting, often within weeks of planting. One would have predicted a similar small percentage of batches would have had very low IRG. However 45% of the seedlots tested had an IRG of less than 2. There were many instances where very poor IRG resulted in very good survival and vice versa.

The nursery outplanting results question the predictive abilities of RGP and suggest poor accuracy. The high within-test variation suggests poor precision. Reported differences in testing procedures (Heywood-Farmer, pers comm.) and variation between observers conducting the test (Scagel, unpubl.) suggest poor repeatability.

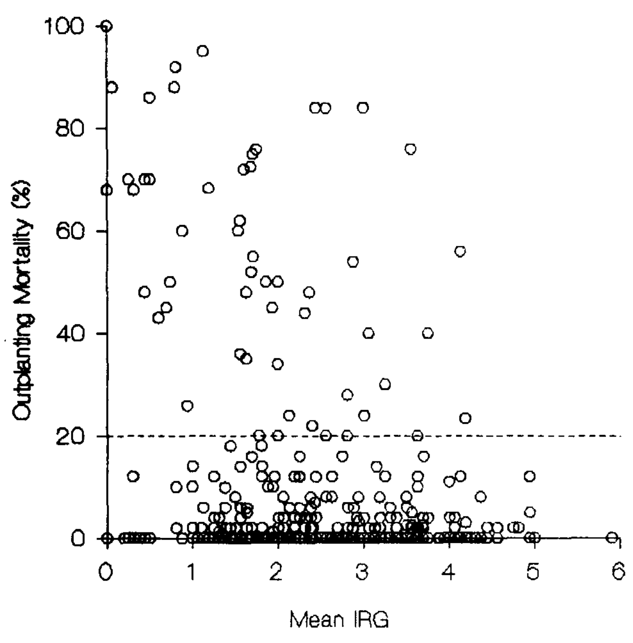

Figure 4.-- Operational IRG related to two-year nursery outplanting mortality for 540 batches of seedlings. The data includes 12 species and numerous stocktypes tested over two years by the BC Ministry of Forests Nurseries. The horizontal line indicates an unacceptable mortality of 20%. Figure '1 expresses this figure to yield interpretations of IRG given in Table 1.

CONTROLLED IRRIGATION OUTPLANTING

Although nursery outplanting plots are neither irrigated or fertilized, it has been argued that these environments are not extreme enough to indicate differential RGP-related mortality. Burdett (1987) attributes the hypothesis of site-specific RGP-related mortality to Stone (1955). That is, only stock with high RGP is capable of surviving on harsh sites, while low RGP stock can only survive on less extreme sites.

Scagel et al. (in prep.) examined this hypothesis in an irrigated farm field trial modeled on the work of Blake *et al.* (1979). Three irrigation regimes were used:

- dry - no irrigation
- fresh - irrigated every second week
- moist - irrigated every week

Three stocktypes of the same seedlot of coastal Douglas-fir grown at a single nursery were used. Several liftings of seedlings were made in expectation of realizing a wide of IRGs (Figure 5). A wide range of IRGs were obtained.

Figure 5 illustrates the two-year outplanting mortality for each of the irrigation regimes. The within-test variation was similar to that presented in Figure 3. There was no consistent ranking of stocktype-liftdate mortality over the three irrigation regimes. Longer storage was associated with a decreased 1RG but was of no consequence to general survival. As observed in the nursery outplanting plots, most death occurred within the first year - most death within weeks of planting.

The only suggestion of a relation between outplanting mortality and IRG occurred on the dry site. On the dry site all stocktypes and lift dates had unacceptable mortality. Unacceptable mortality also occurred on the other two sites. There were no IRG-related relative growth differences but there were large site-related growth and form differences.

The physiological impediments to seedling survival and performance imposed by the plantation environment are critical considerations in stocktype selection and stock quality evaluation. Quality is fitness for purpose (Sutton 1980). These results suggest RGP offers only limited prediction of seedling survival. These predictions might be applicable to extreme environments but the within-test variation mediates against such strict interpretation. Although RGP may have some accuracy, the precision is low.

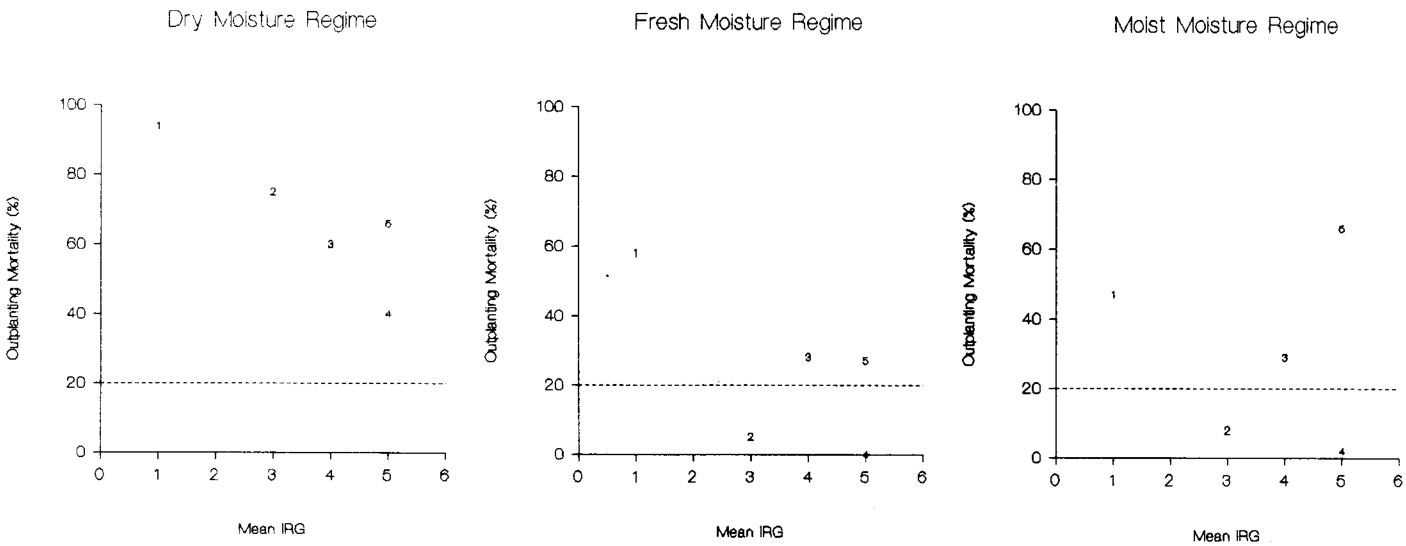

Figure 5.-- Mean ING of various liftdates and stocktypes of Douglas-fir related to two-year mortality in three controlled environments. The horizontal line indicates an unacceptable mortality of 20%. 1, January-lifted plug-transplant; 2, January-lifted 2+0 bareroot; 3, December-lifted PSB 313; 4, January-lifted PSH 313; 5, February-lifted PSB 313.

OPERATIONAL OUTPLANTING

The acid-test of the utility of RGP as a stocky quality grading tool is not how well the test predicts outplanting mortality under carefully controlled research trials. The utility of the test is determined under operational plantation conditions.

Scagel et al. (in prep.) followed three seedlots of coastal Douglas-fir over a range of operational plantation environments on southern Vancouver Island. The sites studied were all suitable for Douglas-fir. The seedlots followed had very similar, high IRGs. According to the RGP test interpretation, these seedlots would be expected to have low mortalities.

The two-year outplanting mortality is given in Figure 6. The within-test variation was similar to that shown in Figure 3. Halt of the plantations had an unacceptable mortality but there was little mortality observed in the nursery outplanting trials. As observed in nursery outplanting plots and irrigated field conditions, most mortality occurred within the first year - usually within weeks of planting. Excavation of dead and poorly growing seedlings indicated that microsite selection and site preparation were the primary factors determining mortality. Unlike mortality, growth correlated with plantation ecosystem. Inspection of planting reports indicated that there had also been delayed planting with attendant stuck handling problems.

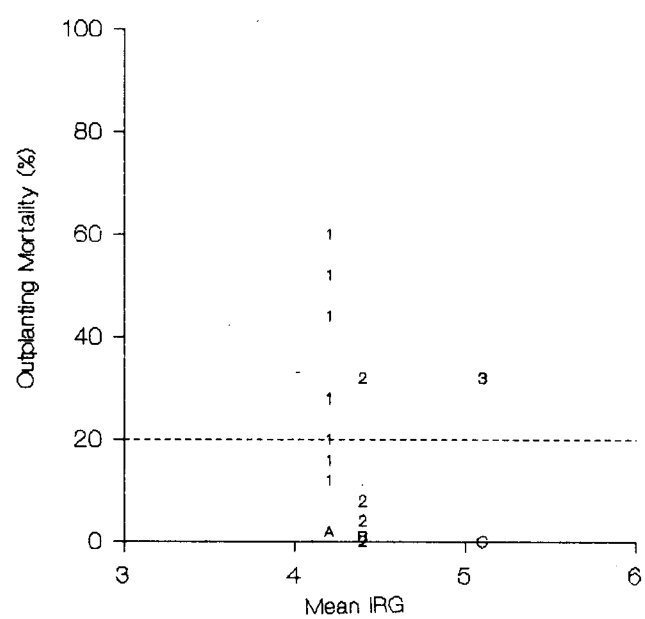

Figure 6.-- Mean IRG of three Douglas-fir seedlots related to two-year operational outplanting mortality in commercial plantations and nursery outplanting plots. The horizontal line indicates an unacceptable mortality of 20%. 1, 2+0 bareroot; A, nursery outplanting mortality of 1; 2, 2+0 bareroot; B, nursery outplanting mortality of 2; 3, 1+0 PSB 313; C, nursery outplanting mortality of 3.

These observations suggest that RGP differences can be equalized by stock handling and planting. This conclusion should not be surprising as there is no substitute for careful handling and storage, good planting, microsite selection, and microsite preparation.

These results iterate Landis and Skakel's (1988) comments about RGP being only a point estimate of stock quality. That is, the results of an RGP test are felt to be representative for the population at the time the sample was drawn and the test run. A lot of stock handling problems can occur in the two weeks it takes to run an RGP potting trial (hdgren 1984). operationally, any predictive ability of an RGP test can be very quickly altered by poor handling practises.

The same conclusions about accuracy and precision are also clear: RGP appears to have *poor* accuracy and precision. In addition it may not be fast enough for operational silvicultural purposes. The lack of precision and accuracy under operational conditions suggests the test lacks general utility - although this does not mean that the test lacks specific, or special purpose, utility such as for research.

RGP USE

A planted, poor quality seedling can cost triple a mistakenly destroyed acceptable seedling. The silviculture cost increases even more if the costs are considered interest-bearing and the plantation requires replanting. RGP-mediated culling decisions should respect this economic consideration and strive to reject unacceptable seedlings.

"Seedling quality" is hard to define, difficult to quantify and impossible to make error-free culling decisions. There will always be instances where some of the good is thrown out with the bad and vice versa (Figure 'I). This does not mean that seedling quality is not worth investigating. To minimize the acceptance of otherwise low vigor seedlings, both purpose and fitness must be stated.

RGP has value as part of a stock evaluation program but on its own otters only circumstantial evidence about seedling quality. RGP can suggest that seedling quality may be poor, but cannot provide explanations, solutions, or predictions of field performance. other sources of information about the stock and the environment of the planting site are required before a stock quality judgment can be made.

in our experience, RGP tests have proved valuable when stock had been suspected of being poor quality as a result of other information on cultural or storage conditions. In these instances additional information on stock quality was critical in flagging suspect batches, repeated potting trials of large number of seedlings corroborated the suspicion, and additional information provided explanations for poor seedling quality.

Like a traffic light, we propose three general decision-making procedures be considered in interpreting the results of an RGP test (Table 1): reject, reserve, caution. These procedures reflect our position that RGP may have value only where extreme values are reported. Figure 7 emphasizes the chances of accepting poor quality batches. There is always a chance of accepting poor vigor stock - 10% of the high 1kG batches had an unacceptable mortality.

Regardless of the test results. the test conditions and variability within the test should always be considered. We recommend that other sources of information about stock should be routinely considered even though they are indicated in Table 1 as optional. Many physiological and morphological tests have been devised and can be used (Duryea 1985). Knowing the cultural and storage history of the stock is the most important. As well, the plantation environment and the expected physiological impediments to plantation establishment in these environments must be considered.

Returning to the sharpshooters' analogy (Fig. 2), RGP is like a small caliber shotgun not a target pistol. It should be used accordingly.

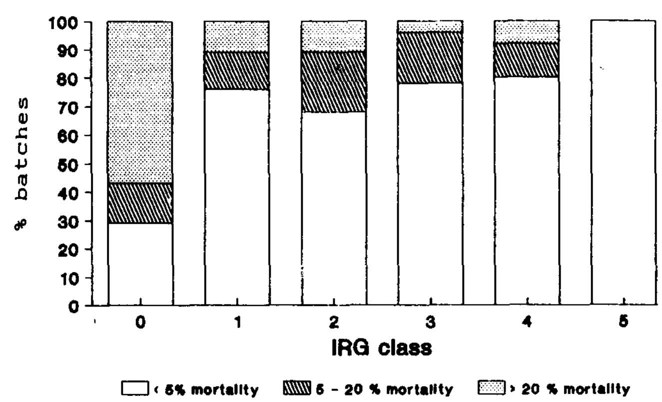

Figure 7.-- IRG interpretation for silvicultural risk. Figure 4 re-expressed to indicate mortality of a mean batch IRG. Mortality is based on nursery outplanting results.

Table 1 -- Decision making recommendations concerning RGP test results. Data are based on 540 operational RGP tests and nursery outplanting plot results. These results pool all species and stocktypes.

	RGP Interpretation Status		
	Red	Yellow	Green
Decision	Automatic rejection	Reserve decision Consider other info	Caution
Parameters			
mean IRG[1]	0	<2	>2
Chance of accepting an unacceptable batch[2] See Figure 7.	<1%	50%	10%
Additional stock information requirement	Not usually required	Required	Maybe
Type of information			
Test conditions	+	+	+
Purpose	(+)	+	(+)
Pathology	(+)	+	(+)
Morphology	(+)	+	(+)
Physiology	(+)	+	(+)
Storage history	(+)	+	(+)
Cultural history	(+)	+	(+)

[1] IRG from Burdett (1979).
[2] "unacceptable" is considered greater than 20% mortality in a nursery outplanting plot. Actual plantation conditions could require adjusting IRG limits.
+ collect other information; (+) other information optional.

SUMMARY

Under present operational testing regimes the accuracy, precision, and repeatability of RGP is low enough that stock quality assessments performed solely on RGP are suspect. An RGP test does not absolve the forester or nurseryman from the responsibility of looking closer at the seedlings that are being purchased - particularly during their nursery tenure. Combinations of methods as well as cultural and silvicultural considerations must be used in decision-making processes concerning stock quality.

Owing to the inconsistency and variability of RGP test results, one must question whether predicating the utility of other methods of assessing stock quality on a comparison to RGP is appropriate. We also question the appropriateness of transferring research technology with these limitations to a fully operational stock evaluation program.

These conclusions are not surprising as seedlings are sensitive to temperature, moisture, nutrients, and aeration. This sensitivity is exploited daily in a nursery environment. How seedlings respond to their environment is a function of their cultural history and current developmental state. Rigorous stock evaluation must consider the dynamic and interdependent nature of biological systems. To assume otherwise is to consider seedlings little more than widgets.

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