Root Growth Potential as an Indicator of Outplanting Performance: Problems and Perspectives[1]

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Abstract.--Root growth potential (RGP) tests have not always proven to be good predictors of outplanting performance under operational conditions. Problems include sample collection, handling, and storage; testing environment; root growth rating system; species differences; outplanting site conditions; and development of an accurate and precise prediction equation. Unless better prediction equations can be developed or threshold points defined, RGP tests should be used primarily as a test of seedling vitality, not relative vigor.

INTRODUCTION

Seedling quality is one of the most widely discussed topics in nursery and reforestation science these days. The 1984 Evaluating Seedling Quality workshop focused new attention on the subject, and the workshop proceedings are considered a primary reference (Duryea 1985). Following this workshop, many nursery managers and reforestation specialists became inspired and either built their own seedling testing equipment or initiated a regular program of seedling quality analysis by independent testing facilities.

Of all the various seedling quality tests, root growth potential (RGP; also called root growth capacity - RGC) is probably the most widely-used, and can be defined as a measure of the ability of a seedling to produce new roots when growing in an ideal environment (Ritchie 1985). The RGP concept is intuitively attractive - more new roots means better survival and growth (Sutton 1980). RGP tests are currently being used by many reforestation foresters as a way to predict the outplanting performance (either initial survival or subsequent growth) of a group of nursery seedlings.

After several years of trying to analyze and apply the results of RGP tests, however, a certain backlash has developed. Many foresters are finding that there is considerable variability in their test results, and that they are not always good predictors of field survival and growth. Binder and others (1988) present results of large-scale operational trials that attempted to predict outplanting performance with RGP tests, and discuss the limitations of this practice. One of the problems is that many nursery managers and foresters tend to oversimplify some of the basic concepts inherent to RGP tests. Actually, the problem may not be the tests themselves, but how they are applied. The situation is analogous to using a pipe wrench to tune-up the carburetor on your car - there is nothing wrong with the tool itself, only the *way* that you are trying to use it.

USING RGP TESTS TO PREDICT OUTPLANTING PERFORMANCE

RGP tests from research laboratories have generally been found to correlate relatively well with seedling outplanting performance, either survival or growth after outplanting. Burdett (1987) provides a listing of the principal studies.

One way to introduce the relationship between RGP tests and outplanting performance is to examine an array of RGP test results, and outplanting performance over a variety of real-life situations. The following table presents different combinations of RGP test results taken at two different times: a pre-shipping test at the nursery and a

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pre-planting test in the field. These test results can be arrayed against various outplanting performance scenarios:

	RGP Test Results		Outplanting
	Pre-shipping	Pre-planting	Survival
1.	GOOD	GOOD	POOR
2.	POOR	GOOD	GOOD
3.	POOR	POOR	GOOD

In situation 1, nursery stock was in good condition at the nursery, it was shipped, handled and stored properly, and planting quality was good. However, site conditions were not conducive to good survival. Even under the best seedling quality and handling procedures, seedlings may not survive under extreme site conditions.

The stock in situation 2 was in poor condition at the nursery. Handling and site conditions were ideal, however, resulting in good survival in spite of poor stock quality. It is also possible that the nursery test was in error; sampling procedures, shipping timeliness and quality, or errors in testing are problems that can confound RGP test results.

Situation 3 has posed a dilemma for many foresters. The reason for poor RGP test results, but good field performance is simple, however. Outplanting performance is a function of two factors: seedling quality and outplanting site conditions (Sutton 1987). Seedlings of poor quality will perform much better on a good site, with ideal outplanting and seasonal growing conditions, than they will under stressful site conditions. Under ideal site conditions, even seedlings with low RGP will survive and grow well.

PRACTICAL SIGNIFICANCE OF RGP TESTS

On an operational level, RGP tests can have two different interpretations:

1. Qualitative. RGP tests are a good indicator of seedling vitality - seedlings that are able to produce a reasonable amount of new roots are obviously alive (Burdett 1987). The RGP test is actually a modification of the traditional "pot test", in which seedlings were planted in containers and placed in a favorable environment to see if they were alive (Binder and others, 1988). As such, RGP tests provide a simple "YES-NO" answer about the viability of the sample seedlings at the time of the test.

2. Quantitative. The second interpretation of an RGP test is that the amount of new roots is somehow related to outplanting performance. To make this interpretation, the new root production must be quantified according to some relative root growth scale, and then a mathematical relationship established with outplanting performance (Sutton 1987). As mentioned earlier, the assumption that more new root growth means better performance than less new new root growth is a seemingly reasonable hypothesis. In the following section, we will discuss some of the problems with this assumption.

REASONS THAT RGP TESTS MAY NOT CORRELATE WELL WITH OUTPLANTING PERFORMANCE

1. Sampling considerations. The number of seedlings used in an RGP test is really quite small and may not be representative of the population at large. A sample of 60 seedlings, which is the number usually required by seedling testing laboratories, is only 0.12% of a moderately-sized seedlot of 50,000 seedlings.

The sample must also be randomly collected from throughout the seedling population. It is relatively easy to collect a random sample when the seedlings are still in the seedbed or on the grading table, but sampling becomes more difficult once the stock has been packaged and stored. It is operationally difficult to sample from bagged seedlings, because a number of bags must be accessed, opened, and the sample collected from throughout the bag, not just from the top layer of seedlings. Sampling during frozen storage would be almost impossible.

RGP test results are only representative of the larger population at time the sample was taken. As soon as the samples are collected, they are under a different set of environmental conditions than the original seedling population, and many things can happen to the original seedlot from the time of lifting until they are outplanted. The RGP rating of a seedlot should remain relatively stable in cold storage, although it has been shown to vary (Sutton 1980), most likely in seedlots that were not completely dormant at the time of lifting.

The timing of RGP tests deserves special mention. RGP test scores will vary with the physiological status of the seedling, particularly in response to its environment. If you are interested in outplanting performance, therefore, the best time to sample the seedlot is as close to the time of planting as is operationally possible. Tests performed on seedlings at the time of lifting will probably not accurately reflect the condition of the seedling at time of planting, although they are useful to evaluate nursery cultural practices.

RGP tests are not instantaneous, either. Most RGP tests take several weeks for handling, shipping and processing so it may take as long as 4 to 6 weeks to receive test results.

2. Poor handling after sample collection. Again, once the samples are collected they are being subjected to different conditions than the original seedling population. Poor handling

practices, poor packaging for shipping to the testing facility, delays during shipping to the testing facility, or a prolonged storage period at the testing facility can seriously affect the test results. Seedlings submitted for RGP tests should be kept cool, packaged in insulated containers, and shipped to insure that they will arrive at the testing facility within 48 hours. In one operational RGP testing program, poor sampling or storage were implicated as the reason for confusing tests results on one sampling date (Zensen unpublished manuscript).

3. Failure to maintain "ideal" environmental conditions during the RGP test. Because it measures potential root growth, RGP tests should be run under greenhouse-like conditions. Burdett (1979) recommends a standard ambient environment of

Day temperature	30° C (86 °F)
Night temperature	25° C (79 °F)
Relative humidity	75%
Daylength	16 hr.
Light intensity	15,000 lux

This standard environment is for the atmosphere surrounding the seedling shoot, however, not necessarily the root. Root environments can vary considerably between the three different RGP testing environments: potted seedlings, hydroponic (aerated water), and aeroponic (mist chamber). Because of the low cost of materials and ease of operation, the hydroponic ("fish tank") RGP test is used by many reforestation foresters conducting their own tests at field locations (Palmer and Holen 1986). Although results from the 3 different test environments have been correlated under laboratory conditions, there may be operational problems in maintaining a proper test environment at remote field sites. Temperature and aeration of the water in the tank are extremely important, as is excluding light from the roots. Root aeration may be especially important with species that are particularly sensitive to flooding injury.

4. The problem of quantifying new root growth. Unfortunately, the root system is the most difficult part of a seedling to observe and measure. Because roots are so fragile and can grow rapidly, measuring new root growth during RGP testing is even more of a problem. Sutton (1987) discusses the difficulty of quantifying RGP and some of the various measurement systems that have been used.

Many people are using Burdett's root rating scale for quantifying the amount of new root growth in RGP tests (Burdett 1979). Because this rating system offers a considerable savings of time and effort In evaluating new root growth and was also one of the first to be published, it has been widely accepted as the standard:

Root Growth Rating	Number of New Roots
0	None
1	Some, none > 1 cm long
2	1 to 3 > 1 cm
3	4 to 10 > 1 cm
4	11 to 30 > 1 cm
5	31 to 100 > 1 cm
6	101 to 300 > 1 cm
7	300 + > 1 cm

Use of this one scale to rate new root growth has obvious advantages:

- It is much easier and faster to count new roots than to measure them.
- Speed of root growth may be more indicative of seedling vigor than total amount of new roots, so this 7-day rating system may be better than other 28-day tests.

but it also has some serious limitations:

- This root rating system was not developed using any morphological or physiological data relating the amount of roots that are necessary for a seedling to successfully become established and grow.
- Different seedling species produce new roots at different rates. The 7-day rating system apparently worked well under laboratory conditions for coastal Douglas-fir [*Pseudotsuga menziesii* (Mirb.)Franco] and a number of other northwestern conifers (Burdett 1987), but some species, such as true firs (*Abies* spp.), do not even initiate root growth for at least a week under these environmental conditions.

5. Failure to recognize physiological differences between species. As mentioned in the previous section, different species have different root production patterns. Compared to Douglas-fir seedlings, ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.) produce fewer, larger diameter roots, which would result in a lower RGP rating using Burdett's scale. Tinus and others (1986) studied RGP patterns for ponderosa pine, Douglas-fir and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) over 4 different environmental stages and found considerable species variation, particularly with ponderosa pine. Using a standard root evaluation scale for all species may lead to faulty conclusions about seedling quality - it may

be necessary to define specific standards for different species or groups of species.

The standard RGP test environment was designed around the optimum growing regime for commercially important tree species, such as coastal Douglas-fir. Different species, and even different ecotypes, grow different lengths and volumes of roots, over different time periods, and at different soil temperatures (Sutton 1980). For example, some true firs, such as noble fir (Abies procera Rehd.), cease root growth at approximately 18 C (65° F), even though common RGP test procedures use root mist chamber or water bath temperatures of 18 to 21 °C (65 to 70 °F). Based on these currently-used test environments, RGP results would be erroneously low for noble fir.

6. Overriding effect of outplanting site conditions. The environment on the outplanting site, particularly soil moisture, is crucial to seedling performance. Under extremely moist conditions, most seedlings will survive irrespective of their RGP ratings whereas under xeric conditions, few seedlings may survive. This "filtering effect" of environment is probably one of the most confounding factors in attempting to correlate seedling quality indices with outplanting survival. Burdett (1987) discusses this conundrum and emphasizes that RGP tests do not predict actual seedling survival, but only survival potential.

7. Defining the relationship between RGP and outplanting performance. One of the assumptions in using RGP tests to predict outplanting performance is that there is an identifiable mathematical relationship between the amount of roots that a seedling can produce under ideal conditions and how well that seedling performs after outplanting. Through the use of regression analysis, a prediction equation can be developed and used to estimate outplanting performance (the dependent variable), using RGP values (the independent variable).

This relationship is probably not a simple linear regression, however, and may involve more complicated statistical manipulations. The addition of other independent variables (multiple regression analysis) may help the precision of the prediction equation; perhaps inclusion of a variable to describe relative outplanting site conditions would be useful. Few relationships in nature can be predicted with one variable and it is naive to assume that outplanting performance is any different.

A more realistic possibility is that there may be a "threshold point" at which the mathematical relationship between RGP and outplanting survival changes form or becomes useless due to excessive variation. This threshold point hypothesis is both logical and useful. Regression analysis assumes that there is a continuous mathematical relationship between the amount of new roots that a seedling can produce and outplanting performance - few roots means poor suvival and growth and more roots means better performance. Actually, under given outplanting site conditions, there is probably some critical number or amount of roots necessary for initial survival: seedlings with fewer roots do not survive whereas seedlings with more roots not only survive but grow in proportion to the number of new roots. Dunsworth (1986) proposes a threshold RGP value of 1.0, using Burdett's scale, as "red light/green light" for determining whether a group of seedlings should be outplanted. An RGC threshold value (10 roots greater than 10 mm in length per seedling) has been proposed as a batch culling guideline for several northwest conifer species (Simpson and others 1988).

CONCLUSIONS AND RECOMMENDATIONS

1. Keep RGP and other seedling quality tests in perspective. There is no single answer for predicting seedling outplanting performance. Because of the complexity and interrelationships involved, we don't currently have, and probably never will have, a single test for measuring seedling quality. To continue with the tool analogy introduced earlier, it takes more than one type of tool to tune-up your car. Other quick, one-test measures of seedling quality, such as the "dormancy meter" (Jaramillo, 1981), have not proven to be operationally useful.

2. RGP is only one aspect of seedling quality, and should be considered in concert with other seedling quality information. Cold hardiness tests, because they are indicative of overall seedling stress resistance, may be more useful for predicting outplanting performance, especially if they include an associated test of seedling vitality. Dunsworth (1986) suggests that measures of stress resistance, such as cold hardiness and dormancy, may be good predictors of seedling survival. Ritchie (1985) proposes that RGP tests are actually reflecting stress resistance, which is more related to outplanting performance than "the ability to grow root per se".

3. The timing of seedling quality tests, including RGP, is important. For reforestation purposes, the best time to monitor seedling quality, including RGP, is as close to the outplanting period as possible because seedling quality can change significantly due to storage and handling. The next best sampling time would be just prior to shipment from the nursery. Seedling quality tests taken during seedling harvesting should be used to evaluate nursery performance rather than outplanting success.

4. It is traditional to conclude these technical papers with the observation that "more research is needed". One productive area of research would be to develop better root growth rating systems that can be adjusted for different species of seedlings. Future research may also clarify the relationship between RGP and

outplanting performance. Perhaps there is some magic formula that will mathematically describe this relationship and allow precise and accurate predictions, although it is doubtful. More likely, future research will reveal a "threshold" RGC rating, which varies with species, that will help to differentiate between good seedlots and ones that are critically weak.

5. This discussion should not be interpreted to infer that RGP tests are useless for predicting outplanting performance. On the contrary, RCP tests do provide some valuable information but, until we can better define the relationships involved, they should be interpreted primarily as a measure of seedling vitality, not relative vigor.

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Author's Note: This paper is the result of informal discussions with many different people, and much of this information is unpublished. Therefore, while we cannot cite their individual contributions, we would like to acknowledge them: W. Lopushinsky, D. Henneman, and D. Simpson.

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