Improving Field Survival of Pine Seedlings and Cuttings: the Sappi Plant Quality Index©

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DEFINING PLANT QUALITY AND ITS MEASURES

Plant quality can be defined as "fitness for purpose" and described as a plant's ability to survive and grow after planting (Mattsson, 1996). Various morphological and physiological plant parameters have been used to measure plant quality in forestry and have been quantitatively linked to increased establishment success (Rose et al., 1990). Many factors can affect plant survival and subsequent growth; these include genetic variability, nursery practice, handling, and transportation of plants as well as silvicultural practices at planting. The potential gains from high quality planting stock in forestry in combination with good silvicultural practices are additive and lead to optimum stocking as well as volume growth (South et al., 2005). The responsibility of nurseries is to ensure that plants with the highest possible chance of survival, that is plants of high quality, are supplied to end users. It is, however, also important to note that producing seedlings and cuttings which meet the desired plant quality specifications do not guarantee that plants will survive, but rather that it guarantees the probability of those plant surviving under normal conditions (Grossnickle, 2012). In much the same way, seed germination estimates the best possible germination under ideal conditions but does not provide a guarantee on the final nursery germination success as this may be confounded by many independent nursery factors.

Transplant stresses are most often associated with water stress in forestry (Grossnickle and Folk, 1993). In order for plants to overcome this transplant stress and successfully establish themselves after planting it is essential that the root system meets the transpirational demands of the shoot system. Immediate root growth and colonisation of the soil as well as sufficient soil contact and good root permeability are essential in this process (Burdett, 1990). It is thus necessary that the plants have functional physiological processes that are required for root growth and development (Grossnickle and Folk, 1993). The relationship between the choice of container size and time in the nursery with differing watering and nutrient regimes can have great impact on plant size, nutrient status, degree of root plug consolidation, and overall health and disease susceptibility. The nutrient, watering, and age requirements for optimum physiological condition for the species in production must therefore be established.

Physiological plant quality measures are very useful in determining plant quality but these are often tedious and time consuming with most commercial nurseries ill-equipped to conduct these measures. Much research since the middle parts of the last century and more recently has focused on developing morphological plant quality measures which can be more easily used by nurserymen to measure the quality of their product and infer some guarantee of physiological quality of the plants they supply. Plant quality recommendations for *Pinus patula* seedlings have been made in Sappi Forests, South Africa, since the mid-1990s. Nurseries were not, however, quantifying the quality of the plants being dispatched. Since 2002 Sappi Nurseries has implemented the "Sappi Plant Quality Index" (PQI) in order to: (1) Quantify and record nursery plant quality, (2) Quality control planting material to eliminate sub-standard plants, (3) Provide a guarantee on the survival and growth potential of plants dispatched, and (4) Ensure the delivery of higher value plants. In this system, easily measurable morphological parameters were identified and ideal specification ranges for each parameter tested for all species for their container type and size (Bayley, 1995, 2000, 2002; Jones and Mitchell, 2005; Morris, 1994). Based on long term trial data, scores were allocated to each parameter reflecting its relative importance to survival and growth in field. Before plants are dispatched from a Sappi Forests nursery, 0.02% of the batch is destructively sampled and measured. Plants are scored on age, height, root collar diameter (highly correlated with root biomass), root plug integrity, leaf colour, presence of ectomycorrhizae, prevalence of white growing tips in roots, signs of disease, and presence of weeds. Critical zero scores are identified and used to flag poor batches which should not be dispatched. A minimum batch score is prescribed and must be achieved before dispatch. By quantifying and scoring such plant quality parameters one is able to predict the initial field survival capacity as well as the growth potential of batches (Grossnickle and Folk, 1993).

PLANT AGE SPECIFICATIONS

Plant age, irrespective of root plug status, can affect field performance as roots become suberized with age and are less able to take up water, particularly after planting when active moisture uptake is essential in ensuring plant survival (Jones and Mitchell, 2007; MacFall et al., 1991; South and Mitchell, 2006). In a containerised system there is a definite ideal age window where plants display the optimum physiology and size for the container size and type. Before this time the plants root plug is not fully colonized which can lead to root damage, loss of plug integrity at planting and ultimately mortality after planting. There is also increased chance that the plants root biomass may not yet be sufficient to rapidly colonise the soil and support the transpirational needs of the shoot biomass once planted out. Plants older than the ideal age window would tend to be highly suberized and also show root defects associated with being root bound, such as deformed root systems and poor root growth. This often leads to poor plant growth, and in trees can lead to basal sweep and wind throw 1 to 2 years after planting.

PLANT SIZE SPECIFICATIONS

Raising the ideal plant size for a specific plug type/volume is very important for both growth and survival potential (Bayley, 1995; Johnson et al., 1996; Ortega et al., 2006; Zwolinski and Bayley, 2001). Seedling height, root collar diameter and sturdiness ratio are important determinants of field performance (Bayley and Kietzka, 1997; Donald, 1992). The heights and root collar diameters (RCD) of plants raised in a containerised nursery system are of vital importance as container size determines the limit of biomass which can be supported. Plants which exceed the size recommendations have a high probability of being root bound, while plants below the recommended size would tend not to have fully colonised the plug. The ratio of height (highly correlated to shoot biomass) to RCD (highly correlated with root biomass) is also an important consideration. When the ratio is high (i.e., shoot biomass: root biomass is greater than prescribed) plants tend to be tall and lanky, hence decreasing stability in the field, which may lead to mechanical damage and mortality. There is also an increased probability that the root biomass may be insufficient to support the shoot biomass under droughty planting conditions. Pine seedlings and cuttings which have a low height : RCD tend to be more sturdy and are less likely to show mechanical damage through wind, and also have a greater likelihood of root biomass being sufficient to support shoot biomass at planting (except if root bound).

ROOT PLUG COLONISATION

The degree to which roots have colonised their root plug is a good indicator of absorptive root surface (Thompson, 1985). Poor root development may be responsible for the plant not meeting the transpirational demands of the shoot system during adverse climatic conditions after planting (Burdett, 1990). Conversely, when root plugs become over colonised (or root bound) pine seedlings and cuttings show a reduction in their ability to produce new roots after planting (South and Mitchell, 2006). This may lead to reduced survival and growth (South and Mitchell, 2006). It is also possible that while early survival and growth may not be effected by being root bound it can still lead to decreased stability in the longer term (Lindström and Rune, 1999). This may lead to trees being blown over at around 1 to 2 years of age. For the reasons listed above seedlings should be planted when they have colonized the root plug but the root plug has not yet become root bound (Bayley, 1995). A root plug is not fully colonised if growing medium falls off the plug and exposes roots at extraction. Ideally root plugs should be fully colonised, firm but not hard, with white root tips (actively growing roots). A plug could be classed as root bound when the plug is hard with many roots visible on outside of plug, a high proportion of which are relatively thick brown roots, forming a dense mat particularly at the bottom of the plug.

ROOT SPIRALLING/COILING AND J-ROOTING

In some container types, lacking root trainers, roots may grow in a circular fashion. This "root spiralling" or "coiling" can lead to infield root deformations which constrict around the main tap root causing decreased stability, and ultimately wind damage and mortality 1 to 2 years after planting (Zwolinski and Bayley, 2001). It is important to score the frequency of this defect and manage batches accordingly. In order to significantly reduce this phenomenon it is advisable to use containers with pronounced internal ridges which prevent root spiralling by training roots downwards (Mitchell et al., 2012). "J-root" formation is a phenomenon that is sometimes a problem with forestry seedlings (Bayley, 2000). J-roots may be artificially formed when the root plug is bent during planting or when young seedlings are transplanted in the nursery (Bayley, 2000) or naturally through large media particles inhibiting vertical root growth downwards. Primary roots with a bend greater than 90° are generally considered to be J-rooted.

PLANT HEALTH

Leaf Colour

The colour of foliage gives an indication of the nutritional status of the plants and of their photoprotection ability (Close et al., 2005). Needles which are deep green are indicative of levels of nitrogen which are too high as increasing nitrogen supply can reduce drought resistance (Etter, 1969; Pharis and Kramer, 1964). These are sometimes referred to as "soft plants." Needles in the light yellow/green to yellow range usually show that nitrogen levels are too low. Nitrogen in the deficient to low range can also reduce drought resistance (Driessche, 1991) and these are referred to as "weak plants." Light green needles show an intermediate and possibly more ideal level of nitrogen where plants are hardy but with sufficient nutrient reserves to survive transplanting.

Mycorrhizae

Beneficial mycorrhizal fungi, naturally colonising most horticultural and forestry plants, can increase disease resistance and enhance water and nutrient uptake (Cuny, 1995; Davies, 2000; Linderman, 1993). The presence of ectomycorrhizae is usually visible as grey to white fungus on the root plug and/or where the tips of roots are swollen or branched (bifurcate).

Disease

Any signs of disease within a pine batch must result in the batch being held back until the disease issue has been remediated. An example of a common forestry disease is *Fusarium circinatum* which has become one of the largest threats to the pine forestry industry in South Africa (Mitchell et al., 2011; Wingfield et al., 2008). Crous (2005) observed that during 2003 and 2005 in the Mpumalanga province of South Africa an average of 25% of planted pine died because of the disease. Mitchell et al. (2011), using the current establishment costs for pitting, planting, and blanking of these areas, estimated this loss to be R602 per ha for the saw timber industry, and R896 per ha for the pulpwood industry, which he estimated cost the industry, as a whole, 11 million rand per annum. Thus, any signs of disease within a pine batch must result in the batch being held back until the disease issue has been remediated. In the case of *F. circinatum* it is necessary to continually rouge out all symptomatic plants as early as possible to maintain low levels of inoculum in the nursery. This usually requires the rouging of less than 1% of a batch which has a much lower economic impact on the industry than the alternative described above (Mitchell et al., 2011). *Fusarium circinatum* symptoms initially manifest as a shoot tip wilt, turning blue/grey and ultimately reddish brown. Roots will be dead and root collar will have resinous staining by the time disease symptoms are noticed. Another common disease in pine nurseries is *Botrytis cinerea* which appears first as a grey to blackish mould on the stem and then seedlings show wilting of the shoot tip. Outbreaks of this disease are often associated with suboptimal nursery practice and are more easily remediated, before dispatch, than *F. circinatum* outbreaks.

IMPLEMENTATION OF THE SAPPI PLANT QUALITY INDEX

The Sappi PQI system is implemented as standard operating procedure at all Sappi nurseries, and has been since 2002. Specifications for pine and *Eucalyptus* species, as seedlings and cuttings, have been researched and established. Each batch produced at a Sappi nursery has a PQI score sheet attached to the dispatch note. This is to allow both the nurserymen and foresters to assess the quality of a batch before dispatch and planting. This also serves to flag any potential quality issues, thus avoiding the significant costs of replanting areas initially established with poor quality seedlings and cuttings. The implementation of the PQI system within Sappi Nurseries is audited annually and training is provided to nursery staff responsible for measuring and scoring plant quality on an annual basis as well. The recommendations are revised annually, based on new trial data and industry feedback, to accommodate necessary adjustments or fine tuning for new challenges.

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