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Predicting first year seedling survival from quality distributions of bareroot seedlings and microsites

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PREDICTING FIRST YEAR SEEDLING SURVIVAL FROM QUALITY DISTRIBUTIONS OF BAREROOT SEEDLINGS AND MICROSITES

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ABSTRACT

Seeding survival has been a continuing problem since the start of the commercial pine plantation in 1950s. The first-year survival of bare-root loblolly pine seedlings at intensively prepared sites in Louisiana has reached a survival plateau of 75 to 85 % with an average of almost 80 %. The major hypothesis of this research was that the survival plateau is a function of the interaction between the frequency distribution of seedling quality and the frequency distribution of microsite quality. This study examined bare-root seedlings and microsite variation, and analyzed the possible options to increase the first-year seedling survival.

The study was approached with simulation and field studies. In simulation study, twenty hypothetical seedling and microsite quality distributions were paired in a manner that simulated 400 plantings. In field study, caliper, stem height, shoot-root ratio, leaf area, and xylem pressure potential were measured for a bale of nursery seedlings and the quality distribution was computed from the seedling volume. Similarly, the microsite variables soil penetration, bed height, moisture content, total mineral nitrogen, and texture were measured and the quality distribution of 8 Weyerhaeuser planting sites was generated from the height increment of associated seedlings. The distributions were combined to predict the first year survival from the assumptions about proportional survival for each pairing.

The simulation results provided initial support to the hypothesis that consistent survival results from random pairing of initial seedling and site quality distributions. The average caliper was 4.22 mm for the seedling sample obtained from a local nursery. The sample contained at least 31 % inferior quality seedlings and, the planting sites contained 21 % adverse microsites. Analysis showed that the significant proportion of inferior seedlings and adverse microsites would result in lower average survival based on assumed survival matrix. The elimination of seedlings below 5 mm caliper of the nursery stock increased the survival to 90 % at the cost of 40.9 ¢ per seedling, an increase of 37 ¢ per seedling.

INTRODUCTION

Seedling survival has been a continuing problem since the start of commercial pine plantation in 1950s (Fox et al. 2007). During 1950s, 60s, and 70s, seedling survival has remained around 70 %, thus maintaining 30 % inefficiency in seedling establishment (Venator 1983, Feret and Kreh 1985). After significant changes during the 1980s in nursery and the site preparation practices, the first-year survival of seedlings increased to a new level (Williams et al. 2003). Survival data from Louisiana Department of Agriculture and Forestry show that first-year survival of bare-root loblolly pine seedlings at intensively prepared sites in Louisiana has reached a survival plateau of 75 to 85 % with an average of almost 80 % (Figure 1).

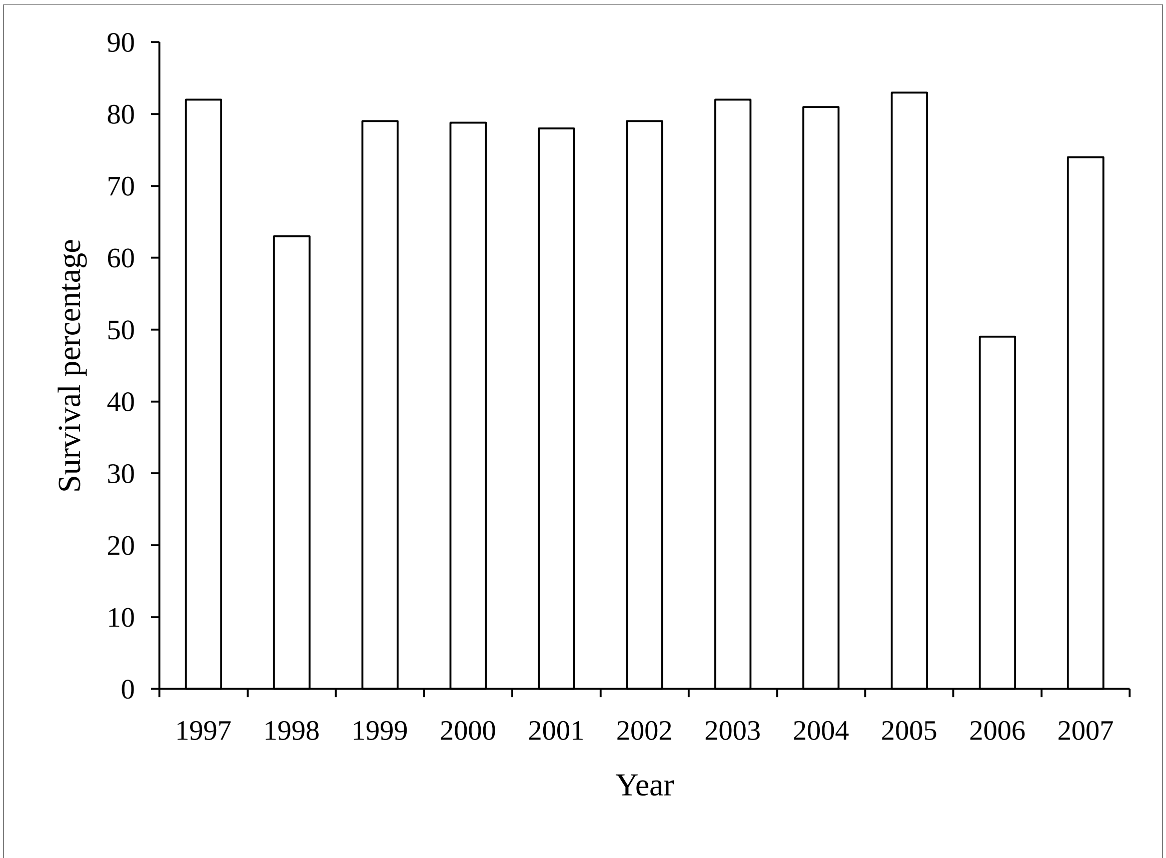

Figure 1: First year seedling survival percentage in Louisiana from 1997 to 2007 (source: Louisiana Department of Agriculture and Forestry).

Various regeneration studies have been conducted to test the survival of nursery seedlings. The studies often report more than 90 % survival success for pine plantation

(South et al. 2001). Fox et al. (2007) found that proper care and handling of genetically improved seedlings ensures more than 90 % survival. However, South et al. (2001) found that there exists a substantial difference in success rate between research studies and operational practices. In research, each seedling is carefully planted whereas in normal operations planters plant seedlings as fast as contract specifications allow.

Industry often plants genetically improved seedlings after mechanical and chemical site preparation and many are later fertilized (Jokela et al. 2004). The survival and growth of seedlings depends on their inherent quality as well as environmental conditions at the planting site (Folk and Grossnickle 1997). Schultz (1999) found that seeding survival can be increased by matching improved genotypes with the site and cultural practices. The success of seedling establishment depends on the use of morphologically and physiologically superior seedlings in a favorable growth environment (Davis and Jacobs 2005).

The reasons for seedling mortality are often uncertain (Wakeley 1954). Past studies reveal various reasons for seedling mortality after planting (Mattsson 1997). Feret and Kreh (1985) found that the mortality of bareroot seedlings was about 30 % because of the following reasons: (i) nursery technique, (ii) transportation and handling care, (iii), planting technique and, (iv) the microsite environment.

The nursery technique involves standardized nursery protocols and subsequent grading to supply seedlings that ensure higher survival and growth after planting (Feret and Kreh 1985). The nursery protocols are standardized in terms of sowing seed, seed bed density, pruning, fertilization, and mycorrhiza inoculation to produce high quality seedlings (Mexal et al. 2002). Furthermore, seedlings undergo certain morphological and physiological grading to single out lower quality seedlings and to supply promising seedlings (Davis and Jacobs 2005).

Dunsworth (1997) pointed out that majority of plantation failures are due to improper transportation and handling of the planting stock. A great deal of attention has been paid to maintain the vigor of seedlings between nursery and planting site so that the seedling possesses same vigor during planting. Using a refrigerated van for storage and transportation has improved the quality of seedlings at the planting site (Fox et al. 2007).

Since the 1950s, mechanical site preparation has become a standard practice in the southern US (Fox et al. 2007). Site preparation typically uses heavy equipment to improve the microsite conditions for seedling survival and growth through improved drainage, conducive microsite environment, and reduced competition (Lincoln et al. 2007). Bedding has been long been prescribed for poorly drained sites to improve first year survival (Fox et al. 2007).

Despite standardized nursery and site preparation practices, first year seedling survival is still less than 90 % on average (Figure 1). The practices pursue standardized protocols during nursery, lifting and transport, planting, and tillage to ensure initial survival and growth (USDA 1989). The nursery and site preparation practices are more integrated to increase the final survival; improved genotypes are suited to the specific planting site conditions to provide the best growing environment for the seedlings to grow to their genetic potential (Fox et al. 2007).

No studies could be found that looks at the outcome of combining a range of seedling qualities with a range of microsite qualities. Furthermore, there is lack of studies describing the frequency distribution pattern of seedling and microsite qualities involved in current plantation practices. According to Burdett (1990) current nursery supply contains a significant proportion of the cull seedlings. South et al. (2001) claims that nurseries supply about 30 % cull seedlings that have a small chance of survival after planting. Schultz (1999)

reported 30 % mortality for the bareroot seedlings in the southern US. These studies did not describe the distribution of seedling quality.

Studies reveal that seedling survival depends on both morphological (e.g. caliper, height, shoot-root ratio) and physiological parameters. Mexal et al. (2002) found strong relation of caliper to the seedling survival and growth. Vanderschaff and South (2006) found that the larger caliper seedlings had better growth and survival than the smaller seedlings. Palacios et al. (2009) found a strong connection between the caliper and seedling establishment. South et al. (2001) stated that the caliper is an important consideration in southern nurseries because of its tie with seedling survival and growth. Knapp et al. (2006) found that caliper was more related to the initiation of height growth of planted seedlings, and found that rapid stem growth was key to the establishment of new seedlings.

South et al. (2001) found that seedling height was positively related with survival and growth. The height of seedling determined the needle frequency which was related to the photosynthetic capacity and the transpiring area of seedling (Thompson 1984). Tuttle et al. (1987) found that the taller seedlings generally had better survival and growth, but on poor sites, planting taller seedlings was not an advantage.

Larsen et al. (1986) found shoot-root ratio as the best quality indicator of seedling quality. Shoot-root ratio was related to water stress status of seedlings immediately after planting and ultimately with its first-year survival. The seedlings with smaller shoot-root ratio were found to be disadvantaged if they lacked the proper root system to support the shoot after planting (Puttonen 1989).

Bronnum (2005) found that planting shock was an important consideration to the newly planted seedlings. The seedlings rapidly loose water during handling and immediately after planting, as they are often exposed to the evaporation demand from atmosphere. Margolis and Brad (1990) found that establishing a functional relation between soil, plant,

and atmosphere to obtain water from the soil to meet the transpiration demand is critical for the survival of plantings. The inability of new seedlings to obtain adequate water impairs photosynthesis, assimilation, and root growth (Bronnum 2005).

Seedling performance is dependent on the growing environment of planting site (Puttonen 1989). One of the goals of site preparation is to create microsites that allow seedling roots to grow to their genetic potential (Dougherty and Gresham 1988). Knapp et al. (2008) found that two primary functions of site preparation are manipulation of soil physical properties and competition control. Jokela et al. (2004) reported that mechanical and chemical site preparation, bedding, and fertilization as the standard site preparation practice in intensive industrial operations in the southeastern US. The treatments either increase soil resources or enhance the ability of seedlings to garner resources and increase survival and growth (Lincoln et al. 2007). In particular the changes in nutrient and water availability have significant influence on photosynthetic efficiency of needles and the survival of seedlings (Jose et al. 2003).

Morris et al. (2006) found that seedling growth of the newly planted seedlings is a function of soil properties such as mechanical resistance, water potential, and aeration. Lincoln et al. (2007) found that the mechanical site preparation reduced soil penetration resistance and supported the root growth of seedlings. Burney et al. (2007) mentioned that the high compaction resulted reduction in macropores, root space, and water availability, which ultimately reduced the root growth. In artificial compaction study, increase in compaction level reduces seedling growth (Brais 2001). High soil strength and poor aeration were the primary causes of growth limitation at high compaction (Siegel-Issem et al. 2005).

The amount of soil water content determined the rate of root growth because it alters the mechanical resistance and aeration condition of soil (Morris et al. 2006). The ability of soil to resist compaction is a function of texture, organic matter content, and water content in

soil. The combined interaction of bulk density, soil strength and porosity which are dependent more on the moisture level affect the root development ultimately leading to inefficient growth of seedlings (Miwa 2004).

Margolis and Brad (1990) found that nitrogen is the most limiting nutrient for seedling growth. In coastal plains of the South, soil nitrogen is one of the most limiting factors because of its vulnerability of loss during harvesting and regeneration. Application of nitrogen fertilizer increases its availability and net photosynthesis, resulting in more biomass production (Zhao et al. 2008). According to King et al. (2006), fertilization increases leaf-specific photosynthesis and increases the diameter, height, basal area, and volume of fertilized pines compared to unfertilized pines. Williams et al. (2003) found that amount and timing of nitrogen fertilization on bareroot loblolly pine seedlings alters their morphology, survival and growth. Fertilization also increases water-use efficiency of seedlings (Albaugh et al. 2004).

Fox et al. (2007) found bedding as an important site preparation practice in the southern US. Bedding increases seedling growth because it improves the root aeration and reduces shrub competition. Dougherty and Gresham (1988) found that bedding improved drainage and aeration condition at rooting zone because bedding enhances root growth and contributes to increase the first-year survival. Zhao et al. (2008) found that bedding reduced the surface drainage problem and supported the seedling growth.

Seedling survival within a plantation can be treated as the result of the random pairing of seedlings and microsites. Planting randomly combines seedlings and microsites from an underlying distribution. The planting crews assign randomly selected seedlings to the randomly selected microsites. Ultimately, interaction of the quality of seedling and planting site determines seedling survival. There are two ways to evaluate this hypothesis. One method involves simulating the planting process by combining the frequency distributions for

seedling and the microsite qualities. The other method involves measuring the quality distribution of seedling lots, assessing the microsite quality distribution within plantation blocks, and measuring the survival of selected seedling with distribution at the known microsite quality distribution.

Simulating the planting process involves assuming the frequency distribution for seedling and microsite quality, and combining the distribution to get the relative frequency distributions of the pairing. This approach simulates the planting process where a seedling is pulled at random from the planting bag and planted on a random spot on the site. This approach simulates the planting process where a seedling is pulled at random from the planting bag and planted on a random spot on the site. The combination of each quality with all available site quality classes makes a complete pairing of all possibilities. Overall survival percentage is determined by an arbitrary decision table for the survival of each combination of seedling and microsite quality classes. Proportion of surviving seedling population in each combination is computed by multiplying the relative frequency of each pairing with corresponding relative frequency in decision table. The total survival of this simulation is the sum of the proportion of surviving seedling population in each cell. Different plantings can be simulated by varying either the frequency distribution of seedling quality or microsite quality or both.

Quality is obviously an abstract ideal. To be useful the seedling and microsite quality must be translated to measurable variables. The outcome of the random pairings of seedling and microsite qualities in simulation study is based on the arbitrary rules. The hypothetical distributions of seedling and site quality might not resemble actual distributions. Thus translating the quality trait of the simulation to field is not direct. Quality must be put in terms of measurable seedling behaviors, and the seedling survival and growth must be measured under uniform microsite conditions to quantify the distribution of seedling quality. The

survival and growth must be measured on genetically identical seedlings planted on a site to measure the distribution of microsite quality. Seedling variation in uniform microsite separates the seedling quality variation effect, while the variation in response of the genetically identical seedlings at heterogeneous sites isolates the variation in microsite quality. In addition, to develop the survivorship table, seedlings of known quality distribution must be planted on a site of a known distribution of microsite quality. The reciprocal planting would provide the effects of initial seedling and microsite quality on survival and height growth of the plantings. Outcome would be survival primarily and growth secondarily.

RESEARCH OBJECTIVES AND HYPOTHESES

The primary purpose of this research was to investigate the effects of seedling and microsite quality variation on first year seedling survival in industrial pine plantations. Specific objectives of this study were to

(i) determine the variation in seedling and the microsite quality, and

(ii) examine the possible means of increasing first-year survival through changes in quality distribution of seedlings and microsites.

The major hypothesis of this research was that the survival plateau is a function of the interaction between the frequency distribution of seedling quality and the frequency distribution of microsite quality.

MATERIALS AND MEHODS

The objectives of this study were approached with a simulation study and field studies. The simulation study involved testing the hypothesis with hypothetical distributions. The field studies measured the variation in variables related to the survival and growth.

SIMULATION STUDY

In the simulation study, 20 hypothetical seedling and microsite quality distributions were created and paired in a manner that simulated 400 plantings. The distributions varied from highly skewed to normal but they were all unimodal. The assumed distribution of 20 seedling lots and planting sites and the survival result of their pairings is attached in appendix. The objective of the simulation study was to test the feasibility of the hypothesis and to analyze how the final survival responds to variation in initial frequency distributions of seedling and microsite quality. The following example illustrates the approach.

Hypothetical Distributions of Seedling and Microsite Quality

Seedlings were divided into four quality classes and given various relative frequencies. For this example, quality classes '**a**', '**b**', '**c**', and '**d**' were assigned relative frequency of 0.15, 0.25, 0.40, and 0.20 respectively (Table 1).

Table 1: A hypothetical seedling quality distribution

Quality class	Relative frequency
a	0.15
b	0.25
c	0.40
d	0.20

Similarly, microsites were divided into four quality classes '**a**', '**b**' , '**c**', and '**d**' and assigned relative frequencies of 0.10, 0.35, 0.50, and 0.05 respectively (Table 2). The relative frequencies were arbitrarily assigned.

Table 2: A hypothetical relative frequency distribution of microsites

Quality class	Relative frequency
a	0.10
b	0.35
c	0.50
d	0.05

Simulating Planting

Planting was simulated with repeated random pairings from the seedling and site quality distributions. This is equivalent to multiplying the relative frequencies of the respective two distributions. Multiplication of the relative frequency of each seedling quality class in Table 1 with each microsite in Table 2 generated a 4 × 4 table of their pairing (Table 3).

Table 3: Relative frequency distribution of the pairings of the hypothetical seedlings and microsites.

Microsite quality	Seedling quality			
	a	b	c	d
a	0.015	0.025	0.040	0.020
b	0.052	0.087	0.140	0.070
c	0.075	0.125	0.200	0.100
d	0.007	0.012	0.020	0.010

Seedling Survival

Because of the range in quality of seedlings and microsites not all pairings were expected to survive after one growing season. An assumption was made about how many seedlings would survive after one year for each seedling and site quality pair. The lower quality pairings of seedling and microsite were assumed to have higher mortality. The '**a**' and '**b**' classes were assumed to be lower qualities and '**c**' and '**d**' classes were assumed to be higher qualities. In this example, the lowest quality class '**a**' of seedling and microsite was assumed to result in death, denoted by 0. The pairings with lower quality classes '**a**' and '**b**'

were also assumed to result in death. The rest of the pairings were assumed to live, denoted by 1 (Table 4).

Table 4: Survival (1) or death (0) after one year for each pairing of seedling and microsite quality.

Microsite quality	Seedling quality			
	a	b	c	d
a	0	0	0	0
b	0	0	1	1
c	0	1	1	1
d	0	1	1	1

The proportion of seedling population surviving in each pairings was computed by multiplying, element by element, the relative frequency of the pairings in Table 3 with the survivorship matrix in Table 4. For this example, the result is shown in Table 5. The sum of values in each cell was the final survival percentage. In this example, the survival is 67.75 % after one growing season.

Table 5: Survival percentage in each pairing of seedling and microsite quality.

Microsite quality	Seedling quality			
	a	b	c	d
a	0	0	0	0
b	0	0	0.140	0.070
c	0	0.125	0.200	0.100
d	0	0.012	0.020	0.010

FIELD STUDIES

The ideal method would be to plant seedlings of known quality at known microsites and measure their first-year survival and growth. This could be practiced by either planting commercially available seedlings on uniform microsites to measure seedling variation or planting clones on operationally prepared tract to measure microsite variation. The survival

matrix could be determined by planting seedlings from known quality classes on microsites of known quality. The measure of the proportion of the surviving seedlings in each pairing after one growing season would give the final survivorship of a particular pairing scenario. The replication results could be used to predict survivorship for a seedling lot or microsites with measured quality distributions.

Limitations of Present Study

No measurements were made on seedlings prior to their planting at Weyerhaeuser sites. The seedlings were already planted at the sites so no information was available about their morphological and physiological variation before planting.

One bale of nursery seedlings was measured. Only 907 seedlings were measured from the purchased bale.

Because of time constraint, the reciprocal planting and the replication of the results could not become possible. The empirical information about first year survival from the planting of seedlings of known quality at microsites of known quality couldn't be conducted.

Seedling Quality Distribution

A small sample of nursery seedlings was measured for their morphological and physiological parameters. The seedling quality class and distribution was developed from these measurements. The relationship among the measured physiological and morphological parameters of seedlings was also analyzed to see how they relate to the survival and growth. The characteristics of seedlings associated with different quality classes were also analyzed.

A bale of nursery seedlings was purchased from the Louisiana Department of Agriculture and Forestry (LDAF) in 2008. The bare-root seedlings were received in a bundle with tops exposed. The pine seedlings were progeny of the first generation seed orchards whose parents had been selected based on superior growth and disease resistance. The supplied bale was stored in refrigerator to keep them fresh.

A total of 907 seedlings were measured from the bale of nursery seedlings to determine the quality distribution. Caliper, stem length, and root length were measured for the selected seedlings. The caliper was measured at the root collar of each seedling. The total height was measured from root collar to the tip of seedling. The root length was the length of tap root from root collar to its tip. The shoot-root ratio was calculated as the ratio of soot length to the stem height.

Out of the 907 seedlings, only 77 seedlings (8.5 %) were randomly selected to measure their total leaf area. Total foliage of each selected seedling was collected in a zip lock bag to measure its area in leaf area meter (LI 3100, LI- COR Inc.). It provided the amount of variation in current nursery seedlings in terms of their projected foliage area.

From the 907 seedlings, only 209 (23 %) were randomly separated to measure their xylem pressure potential and to out plant. The small sample of seedlings was selected to avoid the long storage time of the bale. The pressure potential was measured on two needles per seedling. The pressure potential of the seedling was an average of the two measurements. To measure the pressure potential, the needle was inserted into pressure chamber with the cut end of the needle exposed outside the chamber and pressure was applied to the needle. The amount of pressure required to cause water to appear at the cut surface of the needle was its xylem pressure potential.

Seedlings were planted at the Burden Center, a research station of Louisiana State University Agricultural Research Center. The site is about 8 kilometers northeast of Louisiana State University campus in Baton Rouge, Louisiana. The site was selected because it is close to campus and provided uniform soil conditions across the site.

The planted seedlings were revisited to assess their survival status after first, third and fifth week of plantation. Only 43 planted seedlings were measured out of 209 original seedlings for their xylem pressure potential and height growth. The successive two

measurements of live seedlings in third and fifth week of plantation were taken to observe the recovery of seedlings from water stress and resumption of height growth at the new site.

The needles of the live seedlings were collected at the first, third, and fifth week after planting and the pressure potential measurements were taken in the lab. The measurement provided information about the recovery rate of seedlings after planting. The pressure potential of the sample needles collected from the selected seedlings was measured by using pressure bomb technique (Waring and Cleary 1967).

The current height of live seedlings was measured the third and fifth week after planting. The stem height was measured from ground level to the seedling tips. The mean, minimum, and maximum were calculated for the caliper, stem height, shoot-root ratio, and leaf area of the seedlings. The height increment was determined from the difference of current and the initial height.

The pressure potential of the seedlings before and after planting was analyzed to study the recovery response. The stress values in successive measurements were analyzed for the live seedlings.

Seedling Quality Categories

Volume of the sampled 907 nursery seedlings was calculated from the caliper and shoot length measurements using the following formula

$$V = (\pi \times D^2 / 4) \times H,$$

where V = stem volume in cm^3, π = constant 3.14, D = diameter in centimeter, H = shoot length in centimeter

Seedling volume calculated from the formula was used as an index of seedling quality. Based on volume, seedlings were classified into 5 quality classes. To make the equal range quality classes, the difference of minimum and maximum volume value was divided by 5. The classes were assigned '**a**' '**b**' '**c**' '**d**' and '**e**' symbols where '**a**' denoted the lowest

class and '**e**' represented the highest class.. The relative frequency of each quality class was calculated from the total frequency of seedlings associated with the quality class.

Microsite Quality Distribution

The objective of this study was to determine the variation in microsite quality. Microsite quality was primarily a function of seedling survival and growth. Physiochemical properties of the local microsites were measured to relate seedling behavior to its microsite.

Height growth was used as an index of microsite quality. Planted seedlings and their microsites were assessed at the planting sites owned by Weyerhaeuser Company. Caliper, initial height, and total height were measured for the selected seedlings. The height growth was calculated from the difference of total height and initial height. In addition, microsite factors such as bed height, soil penetration resistance, soil mineral nitrogen, soil moisture content, and soil texture were measured for the selected seedlings to define their growing environment. Microsite quality distribution was generated from the variation in height increment classes and their relative frequency.

<u>Design</u>

The Weyerhaeuser plantation sites were at least 55 kilometers east of Baton Rouge in Livingston parish, Louisiana. Livingston is one of the parishes with the largest concentration of loblolly pine plantation in the southern United States (Schultz 1999). The microsite parameters were measured for the seedlings planted the previous winter with the assumption that the microsites available were unique for each seedling and so would be the response of individual seedlings to such difference. The seedlings were assumed to be uniform when they were planted.

In summer 2008, eight plantation sites were located within a selected area in Livingston Parish. Four measurement sites were located north of Interstate 12 while the other four sites were selected in south of Interstate 12 to represent the possible variation in

microsites because of the elevated interstate. The adjacent blocks were avoided to select different and representative sites.

The selected plantation sites were all cutover planting sites. Each of the sites had received the mechanical and chemical site preparation, bedding, and fertilization treatments before planting.

In each site, 10 planting rows were selected for measurement. Twenty consecutive planting locations were measured in each row, resulting in 200 microsites per site and a total of 1600 microsites from the 8 plantation sites. The first row was selected considering the availability of the 10 rows to measure. Every alternate row was selected as the next measurement row. In other words, every next row was skipped and the second row was selected for measurement. With the same rule, ten measurement rows were selected in each site.

Measurements

The caliper, current height, and initial height were measured for each seedling associated with the selected microsites. The height from ground level to stem tip was the current height of the seedling. The initial seedling height was determined from the initiation of the height growth this year. The first-year height increment was calculated from the difference of current height and initial height.

Soil texture, penetration, bed height, mineral nitrogen and moisture content were measured for the selected microsites. Soil penetration and bed height were measured at the planting site for 1600 microsites. Soil samples of 160 microsites were collected and analyzed in lab to determine mineral nitrogen, moisture content, and texture.

Soil penetration was measured using a pin penetrometer in four quadrants around seedlings. The penetrometer was pushed into the ground and the measurement was recorded. The reading is an arbitrary scale ranging from 0 to 20. Soil moisture was measured to

standardize penetrometer readings because the penetration resistance varies with soil moisture content.

The bed height was measured using a level and a height pole. Two measurements of bed height were taken from both sides of the bed where the seedling was planted.

Two soil samples were collected from near the 10^{th} and 20^{th} seedling of each row using a soil probe. The soil probe was set to collect the soil from the rooting zone of seedlings, 15 to 25 centimeters below the soil surface. The samples were collected in the zip-lock bag and stored in refrigerator to keep them cool.

The total mineral nitrogen, moisture content, and texture type were determined from the analysis of a total of 160 soil samples. To measure the mineral nitrogen content, approximate 10 gm of soil was weighted for each sample and extracted with 2 N KCL. The sample extracts were shaken at 220 rpm for 1 hr. The extract was filtered in a test tube after allowing it to settle for one hour. The filtrate was analyzed for total mineral nitrogen with a ammonia conductivity detector (Timberline Instrument Model 550 A). The detector determined the total mineral nitrogen content of each filtrate (Bremmer 1965).

The soil moisture was measured to normalize the penetrometer readings. Soil moisture content was determined gravimetrically. Approximate 10 gm of soil sample was dried for the next 24 hrs at 60°C until it reached a constant weight. The difference in weight between moist and the dried soil sample was determined and the percentage moisture content was calculated from the following formula,

$$\Delta_{ww} = (\Delta_{ww} - \Delta_{dw)} \times 100 / \Delta_{dw}$$

where Δ_{ww} is moisture percentage, and the subscripts ww and dw denote the wet and dry weight of soil.

Soil texture was determined from the hydrometric method (Klute 1986). Approximate 20 gm of soil was weighted and shaked overnight in a 100 gm/ml SHMP (sodium

hexametaphosphate) solution. Another 20 gm soil was weighed and oven dried at 90°C and weighted again for correction calculation. The solution was filtered through 270 mesh sieve to a 1000 ml cylinder. Sand did not pass through the sieve. The hydrometer reading of solution was then taken after 8 hours. The percentage of sand, silt and clay was obtained from the following formulas:

$$P_{clay} = (R - R_L) \times 100 / \Delta_{dw}$$

where P_{clay} = percentage clay, R = uncorrected hydrometer reading of the solution, and R_L = hydrometer reading of the blank solution.

$$P_{sand} = (C_{ww} / C_{dw}) \times 100$$

where P_{sand} = percentage sand, C_{ww} = weight of moist soil sample, and C_{dw} = weight of oven dry soil sample

$$\%\ Silt = 100 – (P_{clay} + P_{sand})$$

Analysis

The microsite data was processed to calculate the mean, minimum, maximum, and the range of variables measured. Seedling height growth was used as an index of the microsite quality. The height growth range of the 1600 seedlings was divided into 5 equal classes and the frequency of seedlings in each class was counted to determine their relative frequency.

The seedling and microsite variables able to explain the first-year height growth of the seedlings was determined from the stepwise variable selection procedure for the regression models in SAS (SAS 2008, Cary NC). The variation accounted by the significant variables was described.

In addition, a decision tree analysis of the microsite factors determined how the soil variables could classify microsite quality classes. The analysis identified the most important microsite variables and defined the abstract terms microsite class in terms of the values of the variables. The inferior quality sites were defined in terms of the microsite variable values.

Predicting First Year Seedling Survival of Hypothetical Plantings

Seedling quality distribution from the seedling study was paired with the 8 microsite quality distributions from the microsite study to predict the survival of their pairing. The survival of each pairing was predetermined since no empirical data existed for these pairings. To predict final survival of 8 hypothetical plantings, it was assumed that the pairings of lower quality seedlings '**a**' or '**b**' paired with lower quality microsites '**a**' or '**b**' suffered higher mortality, and the mortality in '**d**' and '**e**' quality class pairings were negligible. With such assumptions, four simulation scenarios were analyzed with following two assumptions for each pairing of seedling and microsite quality

i) there was complete mortality in the pairings of either '**a**' and '**b**' for both seedlings and microsites, and

ii) there was partial mortality in the pairings of either '**a**' and '**b**' for both seedlings and microsites

In each simulation, there were 8 final survival values for each of the 8 unique plantation sites. The minimum and maximum survival values of the 8 plantation sites were used to determine the survival range of a simulation scenario, and the average of the 8 sites was the average survival of each planting scenario.

RESULTS AND DISCUSSION

SIMULATION STUDY

Using the given decision matrix in Table 4, survival percentage of 400 hypothetical plantings fluctuated between 0 and 100 % depending on the assumed distribution of seedling and microsite quality classes in each simulation. The assumed quality distribution of 20 seedling lots and planting sites and the expected survival of their pairing is attached in the appendix. The expected survival was responsive to the relative frequency distribution between seedling and microsite quality classes. The higher the relative frequency in '**c**' and '**d**' quality classes, the higher the survival percentage since these pairings were assumed to live. Random pairing of the assumed seedling and microsite quality distributions created a survival distribution tending toward the higher end. The majority of the 400 hypothetical plantings ranged between 60 to 90 % survival (Figure 2). These results provided initial support to the hypothesis that consistent survival results from the random pairings of initial seedling and site quality distributions. Relatively higher distribution of seedlings and microsites in poor quality classes makes the survival fairly insensitive to initial distributions.

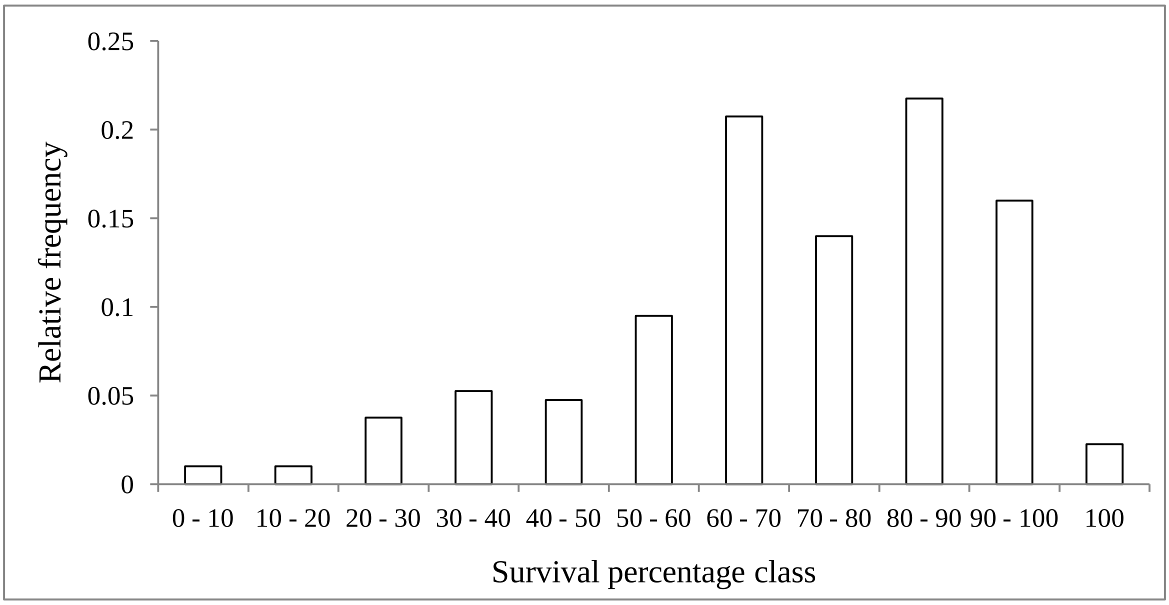

Figure 2: Final survival distribution of the random pairings of 20 seeding quality and 20 microsite quality unimodal distributions (n = 400).

FIELD STUDIES

Seedling Quality Study

The nursery seedlings varied with respect to caliper, stem height, volume, shoot-root ratio, and leaf area. Table 6 suggests that the nursery bale did not contain uniform size target seedlings. Seedling caliper and height averaged 4.05 mm and 25.12 cm, respectively. Vanderschaaf and South (2006) reported a similar finding that the average caliper of the nursery seedlings is 4 mm.

Table 6: The mean, minimum, and maximum for the caliper, shoot, volume, shoot-root ratio, leaf area and xylem pressure potential of the sampled bare-root seedlings before plantation.

Seedling variable	N	Mean	Minimum	Maximum
Caliper (mm)	907	4.05	1.19	8.86
Stem height (cm)	907	25.12	13	39
Volume (cm^3)	907	3.43	0.23	16.02
Shoot-root ratio	907	1.68	0.89	3.12
Leaf area (cm^2)	77	45.45	19.70	111.58
Initial xylem pressure potential (MPa)	209	-5.72	-14.10	-3.90

The average shoot-root ratio was 1.68 and ranged between 0.89 and 3.12. The shoot-root ratio maintained a direct relation to water balance just after planting (Folk and Grossnickle 1997). Larsen et al. (1986) reported that seedlings with heavier roots possessed smaller shoot-root ratio and better survival because of their enhanced ability to collect water and initiate the establishment process. The shoot-root ratio was of limited use to indicate water balance and survival of seedlings after planting (Burdett 1990).

Initial xylem pressure potential varied among the seedlings. The range of the pressure potential was between -14.10 and – 3.90 MPa and the average was -5.72 MPa. The variation indicates that the seedlings were with diverse physiological vigor. The sample of nursery seedlings varied both in terms of their physical and physiological attributes; consequently, the seedlings would be expected to vary in their survival and growth potential.

Leaf area per seedling was significant (P = 0.0045) but weakly related (R^2 = 0. 10) to the seedling volume (Figure 3). Thompson (1984) found that stem volume determined the needle frequency, which was related to the photosynthetic capacity and transpiration area of seedlings. The greater stem volume would have supported higher needle frequency and leaf area. Burdett (1990) reported that leaf area maintains a direct relationship with water loss, but the role of area should be considered relative to water absorbing capacity of the seedlings.

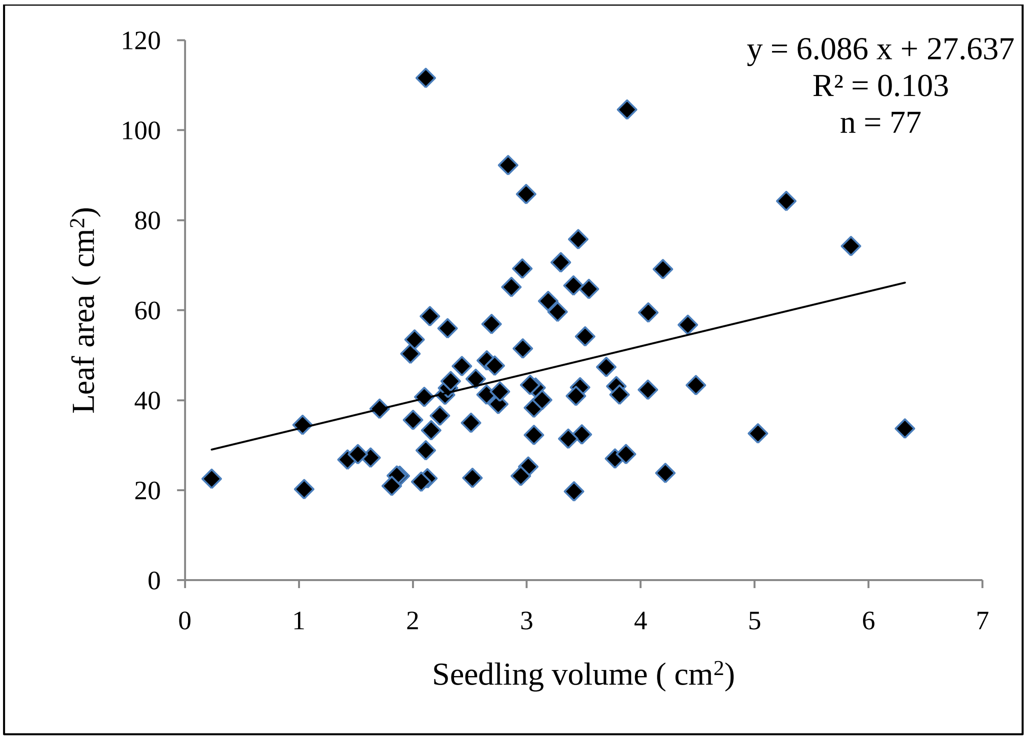

Figure 3: Scattergram of leaf area and stem volume per seedling. Line is fitted with ordinary least squares regression.

<u>Out Planting Survival and Growth</u>

Out of the 209 plantings, 43 were assessed in morning for xylem pressure potential after first week (Table 7). The average xylem pressure potential after first week was -11.48 MPa and ranged between – 19.80 and – 2.50 MPa. The new plantings undergo low xylem pressure just after planting because of the lack of proper root system to connect with the available soil water at the new site (Folk and Grossnickle 1997). Davis and Jacobs (2005) suggested that the poor root proliferation and limited root to soil contact were the contributing factors to low xylem pressure of newly planted seedlings. The value averaged

-11.76 MPa for the live 40 seedlings after 3 weeks, and the average for the remaining 38 live seedlings out of 43 subsample was – 11.23 MPa after 5 weeks of planting.

The average, minimum, and maximum xylem pressure potential values between the measurement times were very close. The seedlings had less than -10 MPa average xylem pressure potential in successive 3 measurements after planting and the values differed by less than 1 MPa. This might be because of the rain and moderate temperature during the period. The xylem pressure potential could be expected to increase gradually with the increase in time since the last rainfall. The seedlings were planted in May 2009 and the successive three measurements were made in June. During the sample collection in morning, the minimum air temperature at Burden Center varied between 14 and 26 ° C and the maximum air temperature varied between 26 and 37 ° C. There was 0.033 mm rain before first measurement and 0.86 mm rain before fifth measurement at Burden center. The fair rain and moderate temperature condition might have contributed to keep the xylem pressure potential values so close.

Table 7: The mean, minimum, and maximum xylem pressure potential of 43 subsample of the planted bare-root seedlings at various weeks after planting at the Burden Center.

Time	N	Xylem pressure potential (MPa)		
		Mean	Minimum	Maximum
1 week	43	-11.48	-19.80	-2.50
3 weeks	40	-11.76	-18	-1.50
5 weeks	38	-11.23	-22.50	-3.20

Figure 4 shows that shoot-root ratio and xylem pressure after 5 weeks was not significant (P = 0.0619) at 0.05 and weakly correlated (R^2 = 0.015). Davis and Jabos (2005) reported that the moisture status was related to the environmental condition at the site. The seedlings with low shoot-root ratio had lower xylem pressure potentials because of their larger shoot size and inability to meet transpiration demands of the shoot. The shoot-root ratio was of limited use to indicate water balance and survival of seedlings after planting

(Burdett 1990). Larsen et al. (1986) reported that taller seedlings with small shoot-root ratio were disadvantaged if they did not possess the proper root system to support the seedlings after planting.

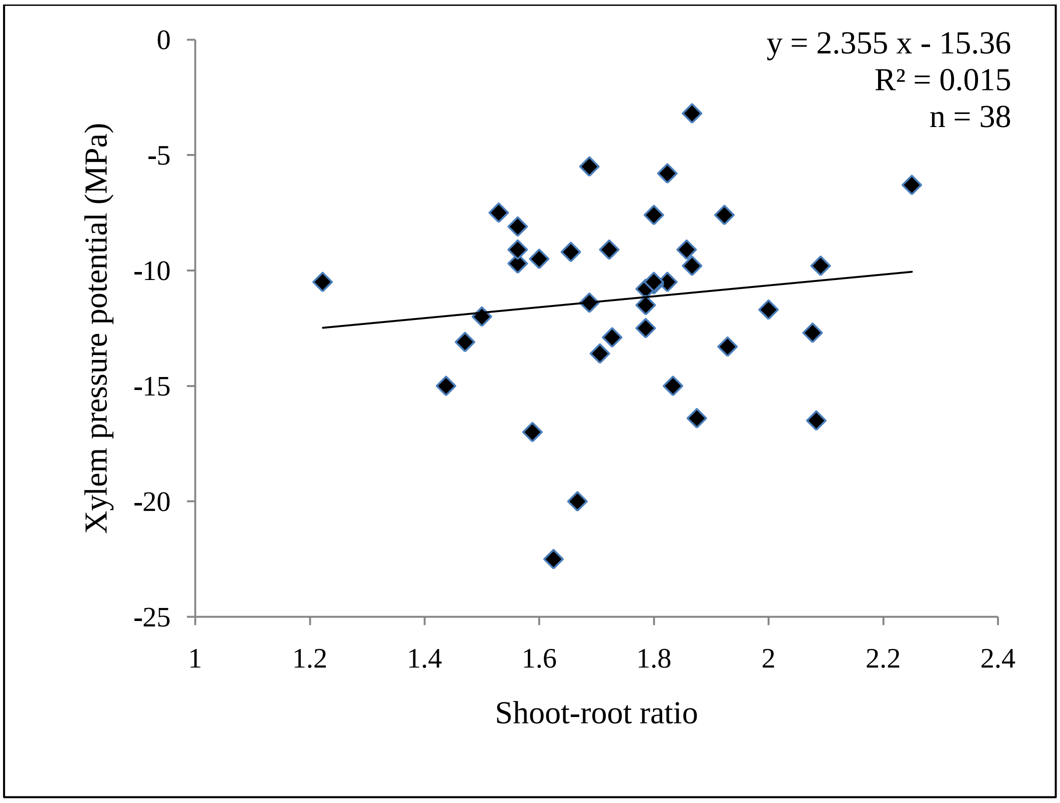

Figure 4: Scattergram of xylem pressure potential and shoot-root ratio after 5 weeks of planting. Line is fitted with ordinary least-squares regression.

The seedlings showed different height growth after planting. The average stem heights were 29.90 and 40.71 cm after 3 and 5 weeks and the difference between the minimum and maximum height was 20 and 34 cm, respectively (Table 8). The difference in height growth indicates the varied growth response of the seedlings to the planting site. The variation in height growth might be because the seedlings with varied physical and physiological vigor had a unique growth response to the environmental conditions at the planting site. The inherent quality of seedlings and the environmental conditions determine the survival and growth of the seedlings at the new planting site (Folk and Grossnickle 1997). Burdett (1990) claimed that the survival and growth of seedlings to a particular planting site condition depends on the seedling quality, environment, and their interaction.

Table 8: The mean, minimum, and maximum height of 43 planted bare-root seedlings at two intervals after planting.

Time	n[1]	Seedling height (cm)		
		Mean	Minimum	Maximum
3 weeks	40	29.90	20	40
5 weeks	38	40.71	25	59

1: out of a subsample of 43 seedlings.

Seedling Quality Classes

The seedlings consisted of different sizes in various proportions. Seedlings in quality class '**a**' had volume less than 2.63 cm^3 while the quality class **'e'** had greater than 10.52 cm^3 of stem volume (Table 9). Because of lower volume in class '**a**' they were considered small and inferior seedlings. The seedlings in class '**e**' had higher volume, and they were taller and presumably superior seedlings. More seedlings were in poor and below average quality classes making the distribution right skewed. The bale contained 31.4 % '**a**' quality seedlings and 57.5 % '**b**' quality seedlings. Classes '**c**','**d**' and '**e**' contained 11.1 % of the seedlings. This indicates that the bale contained mostly '**b**' class seedlings which could be the target quality class, according to current standards.

Table 9: Relative frequency distribution of 907 bare-root seedlings into 5 quality classes based on their stem volume

Seedling quality class	Volume range	Relative frequency
a	< 2.63	0.314
b	2.63 - 5.26	0.575
c	5.26 - 7.89	0.087
d	7.89 - 10.52	0.019
e	> 10.52	0.005

The seedling quality classes differed in terms of caliper, stem height, and shoot-root ratio (Table 10). Average caliper and stem height increased with the increasing quality class but the shoot-root ratio declined. The average caliper was 3.22 mm for quality class '**a**' and 7.85 mm for the class '**e**'; stem height was 23.18 cm for quality class '**a**' and 29.25 cm for the

class ‘**e**’; but the shoot-root ratio was 1.56 for the quality class ‘**a**’ and 1.94 for the class ‘**e**’. The larger seedlings could be expected to exhibit better survival and growth (South et al. 2001). Larsen et al. (1986) found that seedling survival and shoot-root ratio often maintained a negative relationship, but not always. But, Burdett (1990) reported that the shoot-root ratio is a poor indicator of water balance in plant.

The sample consisted of 31 % poor quality class ‘**a**’ seedlings with 3.22 mm average caliper. South et al. (2001) reported a similar finding that 30 % of the grown seedlings were less than 3 mm. Burdett (1990) mentioned that the bare-root seedling stock includes a significant proportion of smaller dimension seedlings.

The most frequent quality class ‘**b**’ had average caliper 4.22 mm, and the height and shoot-root ratio were 25.75 cm and 1.71, respectively. Since there were 57.5 % seedlings in the given quality class, the caliper 4.22 mm could be the target size of the nursery bale. South and Scott (2004) found 4 mm caliper as the target seedling size of most of the nurseries in the southern US.

Table 10: The mean, minimum (min), and maximum (max) caliper, height, and shoot-root ratio of the bare-root seedlings by respective quality class (n = 907).

Quality	Caliper (mm)			Stem height (cm)			Shoot-root ratio		
class	mean	min	max	mean	min	max	mean	min	max
a	3.22	1.19	4.21	23.18	13	29	1.56	0.89	3.12
b	4.22	3.4	5.28	25.75	17	32	1.71	1.06	3.00
c	5.35	4.64	6.27	27.29	23	36	1.87	1.21	3.00
d	6.28	5.37	6.83	28.19	25	37	1.81	1.47	2.25
e	7.85	6.39	8.86	29.25	24	39	1.94	1.60	2.43

Xylem Pressure Potential and Seedling Mortality

Out of the 43 seedlings measured for initial xylem pressure potential, 5 seedlings died within 5 weeks. Before they died, they had pressure potential close to the minimum xylem

pressure potential values as presented in Table 11. The result was consistent between 1st, 3rd, and 5th week of measurements.

Among 38 live seedlings at the end of 5 weeks, most were in quality class '**b**' because it was the most frequent quality class in the sample, but no seedling was in quality class '**e**' (Table 11). After 3 weeks, the '**a**' and '**b**' quality class seedlings had – 9.37 and -11.67 MPa xylem pressure compared to -11.90 and – 13.75 MPa for the '**c**' and '**d**' quality class. The height increment was 6.75 cm for the quality class '**a**' and 5 cm for the quality class '**d**'. The higher xylem pressure potential and greater height increment trend for the lower quality class '**a**' might be because of their small size and relatively smaller transpiration demand.

After 5 weeks, the trend was different than the third week. After 5 weeks, the '**c**' and '**d**' quality classes had relatively higher xylem pressure potential than '**a**' and '**b**' quality classes. In contrary to week 3, the height increment was greater for the quality class '**c**'. The higher quality class seedlings had greater height increment and higher xylem pressure potential. Davis and Jacobs (2005) stated that the capacity to produce new roots immediately after planting helps overcome initial water stress and rapidly acclimatize at the new site. The rapid root growth after planting helps establish a proper root-soil contact and meet the transpiration demand of the seedlings (Folk and Grossnickle 1997).

Table 11: Change in xylem pressure potential and height growth of 38 live seedlings in different weeks according to their quality classes.

		Xylem pressure potential (MPa)			Average height increment (cm)	
Class	N	1st week	3rd week	5th week	3 weeks	5 weeks
a	4	-13.87	-9.37	-9.02	6.75	11.75
b	27	-10.77	-11.67	-12.24	3.81	9.85
c	5	-13.22	-11.90	-8.66	5.2	13.60
d	2	-10.50	-13.75	-8.40	5	8
e	0	-	-	-	-	-

Microsite Study

Microsite Characteristics

Since no measurements were made on seedlings prior to their planting, for the sake of this part of the study it was assumed that the seedlings were uniform. Average height increment of the 1600 seedlings at the Weyerhaeuser sites was 25.59 cm, and it ranged between 1 and 87 cm (Table 12). Knapp et al. (2008) found that better microsites promote better growth than adverse microsites. The variation in height growth was used as an index of microsite variation.

The microsites varied with respect to the measured variables such as soil penetration resistance, bed height, moisture content, mineral nitrogen, and texture. Average value for penetration resistance was between 4.13 and 9.09 and ranged between 0 and 20. Lincoln et al. (2007) found that seedling growth was higher on microsites with less soil penetration resistance than the sites with higher resistance.

The microsite differed in terms of bed height also. Average bed height was between 20.18 and 26.37 cm, and it ranged between 0 and 50 cm. Fox et al. (2007) found that bedding improves the aeration and drainage condition and reduces shrub competition. Higher beds are better in the southern US because of the frequent occurrence of water logging (Zhao et al. 2008).

The sampled 160 microsites had a wide variation in terms of mineral nitrogen. Average available nitrogen was 2.55 ppm, and it ranged between 0.20 and 10.56 ppm. The wide variation might be because of the variation in texture and structure, which ultimately determines the moisture and nutrient availability of the soil (Margolis and Brand 1990).

In the surface horizon, the average proportion of sand, silt, and clay were 36.58, 54.52 and 8.90 %, respectively. The percentage of sand varied between 5.95 and 74.73 %, silt varied between 16.51 and 75.25 %, and clay varied between 5.34 and 21.26 %.

Table 12: The mean, minimum, and maximum of the microsite variables from 8 Weyerhaeuser plantation sites (n = 1600; samples for lab processing were sampled every 10 microsites).

Microsite variables	N	Mean	Minimum	Maximum
Height growth (cm)	1600	25.59	1.00	87.00
Maximum penetration (unitless)	1600	9.09	1.00	20.00
Minimum penetration (unitless)	1600	4.13	0.00	20.00
Maximum bed height (cm)	1600	26.37	4.00	50.00
Minimum bed height (cm)	1600	20.18	0.00	48.00
Soil moisture (percentage)	160	21.65	1.21	53.18
Total mineral nitrogen (ppm)	160	2.55	0.20	10.56
Sand (percentage)	160	36.58	5.95	74.43
Silt (percentage)	160	54.52	16.51	75.25
Clay (percentage)	160	8.90	5.34	21.26

Microsite Quality Classes

Five quality classes were assigned to the 5 height increment classes calculated from the minimum and maximum increment values. The ‘**a**’ quality class sites had less than 14.5 cm annual height growth, while the ‘**e**’ quality sites had greater than 58 cm height growth per season. The ‘**a**’ quality microsites thus represented the lowest quality microsites, and the ‘**e**’ quality microsites represented the best quality microsites. Other quality classes ‘**b**’, ‘**c**’, and ‘**d**’ had increments between 14.5 and 58 cm per year.

The microsite quality class ‘**b**’ contained 39 % of the microsites. This was the most frequent microsite measured. The quality classes ‘**c**’ and ‘**a**’ were the next common microsites with 28 % and 21 % of the sites measured. The quality classes ‘**d**’ and ‘**e**’ were the least frequent sites with only 9 % and 3 % of the sites measured (Table 13).

Table 13: Classification of the microsites into 5 different quality classes based on the seedling height increment and the corresponding relative frequency of each quality class (n = 1600).

Microsite quality class	Height increment class (cm)	Relative Frequency
a	> 14.5	0.21
b	14.5 – 29	0.39
c	29 - 43.5	0.28
d	43.5 – 58	0.09
e	>58	0.03

Out of the 8 planting sites assessed, each site possessed a unique microsite quality distribution (Table 14). The relative frequency between the quality classes characterized the overall suitability of the planting sites. The higher relative frequency in quality class '**a**' comprised the poor quality planting site. The sites A and F were the adverse sites with more than 70 % of the microsites in '**a**' quality class. The sites B and C had more microsites in below average quality class '**b**'. The sites D, E, G, and H had more microsites in average quality class '**c**' which made them relatively better quality sites.

Table 14: Relative frequency distribution of 8 planting sites into 5 microsite quality classes (n = 200 microsites/planting site).

Planting	Microsite quality distribution				
Sites	a	b	c	d	e
A	0.710	0.280	0.010	0.000	0.000
B	0.250	0.525	0.180	0.035	0.010
C	0.040	0.630	0.295	0.035	0.000
D	0.0750	0.220	0.365	0.235	0.105
E	0.080	0.315	0.460	0.095	0.050
F	0.900	0.095	0.005	0.000	0.000
G	0.075	0.355	0.450	0.100	0.020
H	0.095	0.295	0.390	0.170	0.050

In a multiple regression of height growth against seedling (caliper and initial height) and microsite variables (maximum penetration, minimum penetration, maximum bed height, minimum bed height, moisture, total mineral nitrogen, sand, silt and clay), only 5 variables were significant. The model fitted with significant seedling and microsite factors together described 72.64 % variation in height growth of the first year seedlings (Table 15). Seedling variables, caliper and initial height, described 63.74 % variation in first year height growth while the microsite variables described 8.9 % variation. Initial height described 10.45 % variation in height growth. Total mineral nitrogen was the most important microsite variable to describe 6.10 % variation in seedling height growth.

Table 15: Partial and model R-square derived from the stepwise procedure of multiple regression for statistically significant seedling and microsite variables at Weyerhaeuser plantation (n= 160). The first-year height growth was the dependent variable.

Variable	Partial R-square	Model R-square	Pr> F
Caliper	0.5329	0.5329	<.0001
Initial height	0.1045	0.6374	<.0001
Total mineral nitrogen	0.0610	0.6985	<.0001
Maximum penetration	0.0138	0.7122	0.0072
Sand	0.0142	0.7264	0.0054

In decision tree analysis, the most important microsite variables were maximum penetration resistance, sand content, and total mineral nitrogen (Figure 5). The decision tree is a means of characterizing the microsite quality classes. It determined the most important microsite variables as in regression analysis, and classified the microsites based on the values of the significant variables. The tree analysis provided a measure to identify site quality based on the values of the significant variables.

Out of total 160 microsites with no missing observations, the relative frequency of the '**a**', '**b**', and '**c**' quality classes was 21.9 %, 41.9 %, and 26.9 %, respectively. The remaining classes,'**d**' and '**e**', represented less than 10 % of the microsites across all 8 tracts. This indicates that the classification separated mainly average site and below.

The first variable to group the observations was maximum penetration resistance. The value of 14.5 classified the microsites into two branches. The value >= 14.5 defined the poor quality microsites because in this group 55.6 % microsites were in poor quality class '**a**'. The value < 14.5 defined the average and below average quality microsites. In this group, out of 133 microsites, 30.8 % and 43.6 % microsites were in average and below average quality class.

The sand percentage was the second variable to group the microsites. The percentage of sand >= 30.59 % grouped below average and poor quality microsites. The quality class '**b**' comprised 47.20 % of the microsites, but the class '**a**' contained 23.60 % distribution. In the

other branch, sand percentage < 30.59 % defined average and below average quality microsites. The '**b**' and '**c**' quality classes were with 39.30 % and 47.50 % relative frequency percentage.

The third variable to group microsites was mineral nitrogen. The value >= 6.75 ppm defined the poor quality microsites. About 72.20 % of the microsites were in '**a**' quality class. The other branch < 6.75 ppm defined average and the below average quality microsites. The quality classes '**b**' and '**c**' were with 50.80 % and 19.70 % distributions.

These nitrogen results were not in agreement with the past studies. Rehman (2006) reported that nitrogen fertilization increased the growth of the seedlings. Fertilization is one of the options to increase the seedling growth in the sandy coastal plains of the southern US (King et al. 2006). The sites with greater nitrogen should support higher growth, and lower nitrogen availability could be expected to limit seedling growth rate. The different results in this study might be because dead seedlings would not have utilized any soil nitrogen. Conversely, live seedlings might have been actively assimilating and depleting the nitrogen resource.

The maximum penetration resistance and sand percentage were the identifying factors of the adverse quality microsites. The values of maximum penetration resistance and sand percentage together defined the lower quality microsite '**a**'. The maximum penetration resistance > = 14.50 and sand > = 30.59 % defined the character of the lower quality microsites. Such sites could be defined as the adverse microsites. Therefore, excessive compaction and higher sand percentage in these plantations would characterize adverse growing condition available to the planted seedlings. Palacious et al. (2007) reported that after planting date, soil penetration was the most important factor affecting seedling survival. For the sandy coastal plains of the South, greater sand percentage lowers the nutrient and moisture availability (King et al. 2006).

Class	Frequency	Percentage
a	**35**	**21.90**
b	**67**	**41.90**
c	**43**	**26.90**
d	12	7.50
e	3	1.90
Total	160	100

Maximum penetration

< 14.5

Class	Frequency	Percentage
a	20	15.0
b	**58**	**43.60**
c	**41**	**30.80**
d	11	8.30
e	3	2.30
Total	133	100

>= 14.5

Class	Frequency	Percentage
a	**15**	**55.6 0**
b	9	33.30
c	2	7.40
d	1	3.70
e	0	0.00
Total	27	100

Sand

< 30.59 %

Class	Frequency	Percentage
a	3	4.90
b	**24**	**39.30**
c	**29**	**47.50**
d	5	8.20
e	0	0.00
Total	100%	61

>= 30.59 %

Class	Frequency	Percentage
a	**17**	**23.60**
b	**34**	**47.20**
c	12	16.70
d	6	8.30
e	3	4.20
Total	72	100

Total mineral nitrogen

< 6.75 ppm

Class	Frequency	Percentage
a	9	14.80
b	**31**	**50.80**
c	**12**	**19.70**
d	6	9.80
e	3	4.90
Total	61	100

>= 6.75 ppm

Class	Frequency	Percentage
a	**8**	**72.20**
b	3	27.30
c	0	0.00
d	0	0.00
e	0	0.00
Total	11	100

Figure 5: Decision tree analysis of the microsite variables from the Weyerhaeuser plantation sites (n=160).

First-Year Seedling Survival Prediction

Since the outcome of planting seedlings of known quality at microsites of known quality could not be conducted due to time constraints, first-year survival prediction required assumptions about the proportional survival in each seedling and microsite quality combination. Four different survival scenarios were examined to predict the survival (Table 16).

Table 16: Survival matrix for each pairing of seedling and microsite quality class in four scenarios.

Scenario	Microsite class	Seedling class				
		a	b	c	d	e
1	a	0[1]	0	0	0	0
	b	0	0	0	0	0
	c	0	0	1	1	1
	d	0	0	1	1	1
	e	0	0	1	1	1
2	a	0	0	0	0	0
	b	0	1	1	1	1
	c	0	1	1	1	1
	d	0	1	1	1	1
	e	0	1	1	1	1
3	a	0.75	0.75	0.75	0.75	0.75
	b	0.75	1	1	1	1
	c	0.75	1	1	1	1
	d	0.75	1	1	1	1
	e	0.75	1	1	1	1
4	a	0.6	0.6	0.6	0.95	0.95
	b	0.6	0.95	1	1	1
	c	0.6	1	1	1	1
	d	0.95	1	1	1	1
	e	0.95	1	1	1	1

[1] '0' means no survival, '0.25' means 25% survival, and'1' means 100% survival of the seedlings of given seedling class - microsite class combination.

In the first scenario, all of the seedlings in classes '**a**' and '**b**' when planted on microsites '**a**' and '**b**' would die. All other combinations would live. In the second scenario, all seedling and microsite quality combinations would be successful with the exception of '**a**' quality seedlings planted on '**a**' quality microsites. In scenarios three and four, survival would be variable fractions depending on the specific pairing of quality classes involved.

The expected survival was determined from the pairings of initial seedling and microsite distributions evaluated for each survival matrix scenario. The calculation of the expected survival from the pairings of the seedling quality distribution in Table 9 with the microsite quality distribution of the planting site B in Table 14 for the survival scenario 4 involved following two steps. First, the relative frequencies of seedlings and microsites were multiplied to calculate the relative frequencies of their pairings as presented in Table 17.

Table 17: Relative frequency distribution of the pairings of seedling and microsite quality distribution at the planting site B.

		Seedling quality				
		a	b	c	d	e
Microsite quality		0.314	0.575	0.087	0.019	0.005
a	0.250	0.079	0.144	0.022	0.005	0.001
b	0.525	0.165	0.302	0.046	0.010	0.003
c	0.180	0.057	0.104	0.016	0.003	0.001
d	0.035	0.011	0.020	0.003	0.001	0.000
e	0.010	0.003	0.006	0.001	0.000	0.000

Then, the relative frequencies in Table 17 were multiplied with the survival assumption values of the scenario 4 in Table 16 to calculate the expected survival values. The proportion of seedling population surviving in each pairings was computed by multiplying, element by element, the relative frequency of the pairings. Table 18 presents the expected survival values for each quality class pairing. The sum of the survival values in each cell of this table was the survival average of the planting site B in scenario 4. In this example,

the cell values sum to 0.798 which is presented in Table 19 for the planting site B and scenario 4.

Table 18: Survival percentage in each pairing of seedling and microsite quality distribution at the planting site B for the survival assumption scenario 4.

		Seedling quality				
		a	b	c	d	e
Microsite quality		0.314	0.575	0.087	0.019	0.005
a	0.250	0.047	0.086	0.013	0.005	0.001
b	0.525	0.099	0.287	0.046	0.010	0.003
c	0.180	0.034	0.104	0.016	0.003	0.001
d	0.035	0.010	0.020	0.003	0.001	0.000
e	0.010	0.003	0.006	0.001	0.000	0.000

Similarly, the expected survival was calculated for the pairings of seedling and microsite distributions from 4 different scenarios. The pairing of the single seedling distribution characterized in the seedling study with each of the 8 microsite distributions in the microsite study gave 8 predicted survival values for each survival matrix scenario. The pairing of seedling distribution in Table 9 with microsite distributions in Table 14 was evaluated for each scenario in Table 16. The average and range of predicted survival is presented in Table 19. The average and range of predicted survival of 4 scenarios was computed from 8 survival values for 8 planting sites. The range was the minimum and maximum of each scenario.

In Table 19, the survival values for a scenario varied depending on the distribution of the planting sites. There were 8 different survival values for the 8 planting sites in the scenario 4. This was because of the variation in the initial microsite quality distribution (Table 14) for each planting site, though these 8 planting sites had the same seedling quality distribution (Table 9) and same survival scenario 4. But, the survival values between

scenarios varied depending on both the microsite distributions of each planting site and the corresponding survival scenario.

Table 19: Expected first-year survival from the seedling and microsite distributions based on 4 different survival scenarios.

	Scenario			
Planting site	1	2	3	4
A	0.001	0.199	0.800	0.677
B	0.025	0.515	0.879	0.798
C	0.037	0.659	0.915	0.849
D	0.078	0.635	0.909	0.885
E	0.067	0.631	0.908	0.860
F	0.001	0.069	0.767	0.632
G	0.063	0.635	0.909	0.857
H	0.068	0.621	0.905	0.865
Average	**0.042**	**0.495**	**0.874**	**0.803**
Minimum	**0.001**	**0.069**	**0.767**	**0.632**
Maximum	**0.078**	**0.659**	**0.915**	**0.885**

The scenarios 1 and 2 did not match the survival values reported by Louisiana Department of Agriculture and Forestry. In scenario 1, average first-year survival was 4.2 % and the range was between 0.1 and 7.8 %. In scenario 2, the expected first-year survival was 49.5 % and the range was between 6.9 and 65.9 %. The average survival percentage was too low and the range did not include most common survival rates reported by LDAF for pine plantations. In scenario 3, the expected survival averaged at 87.4 %, and the range was between 76.7 and 91.5 %. The results were better than the other two, but the average and range were higher than the observed rate.

In scenario 4, the average expected first year survival was 80.3 %, and the range was between 63.2 and 88.5 %. This matched the first-year seedling survival reports of average 80 % and range between 70 and 85 % reported by LDAF in real plantations. The expected range of first year survival included the observed survival range and the average was closer to the observed rate. This survival matrix scenario seems to represent the current plantation practices. It implies that the plantation practices might be replicating this scenario every year

to result the given average and plateau of first year seedling survival. The scenario was selected for further inferences.

The essential characteristic of the quality distributions involved in 400 plantings was that the initial distributions of seedlings and microsites were all unimodal. They might be left skewed, normal, or right skewed distribution. In addition, the selected scenario 4 assumed higher survival proportion for the pairings of better quality class seedlings and microsites.

Application of the Results

This study shows how the combination of seedling and microsite quality distributions can result in a fairly constant survival. The presence of lower quality seedlings and microsites appear to be largest contributor to seedling mortality. Culling of such seedlings and avoiding poor microsites should increase overall survival.

One of the options to increase the survival would be to eliminate the percentage of lower quality seedlings planted at lower quality microsites. To avoid such combinations, the adverse microsites would have to be identified before planting and cull inferior seedlings during the planting operation. Rejecting the lower quality seedlings and avoiding the poor quality microsites during planting improved the original nursery seedling and Weyerhaeuser microsite quality distributions. The new seedling quality distribution is in Table 20.The total usable seedlings were lower than 907 because the seedlings not meeting the minimum size requirement were discarded. The number of usable seedlings in the nursery bale decreased with the increase in minimum acceptable caliper size.

Table 20: The minimum caliper, total usable seedlings out of 907, and their relative frequency distribution.

	Total usable	Seedling quality class				
Caliper > = mm	seedlings	a	b	c	d	e
3	835	0.259	0.625	0.094	0.020	0.004
4	456	0.004	0.777	0.172	0.037	0.008
5	92	0.000	0.097	0.673	0.184	0.043

In each planting site, the number of usable microsites decreased from 200 because the microsites supporting less than 14.5 cm first-year height growth were avoided during planting (Table 21). Depending on the number of '**a**' quality class microsites avoided, the total usable microsites varied for each planting site.

Table 21: Planting sites, total usable microsites out of 200 per site, and their relative frequency distribution.

Planting sites	Total usable microsites	Microsite quality class				
		a	b	c	d	e
A	58	0	0.965	0.034	0.000	0.000
B	150	0	0.693	0.246	0.046	0.013
C	192	0	0.656	0.307	0.036	0.000
D	185	0	0.237	0.394	0.254	0.113
E	184	0	0.342	0.500	0.103	0.054
F	121	0	0.834	0.157	0.008	0.000
G	185	0	0.383	0.486	0.108	0.021
H	182	0	0.329	0.428	0.186	0.054

The simulation of the pairing of seedling quality distribution (Table 20) with microsite quality distribution (Table 21) was evaluated for the scenario 4. It increased the average survival. The elimination of seedlings less than 3 mm caliper from the distribution and avoiding the lowest quality microsites '**a**' during planting increased the average survival to 89.1 % (Table 22) when the analysis was run for the survival matrix in scenario 4.

Eliminating seedlings less than 4 mm and avoiding the lowest quality microsites increased the survival to 97.6 %. Eliminating seedlings less than 5 mm and avoiding the lowest quality microsites increased the survival to 99.7 %.

Table 22: Average, minimum and maximum expected survival of the seedlings with given minimum caliper planted at each 8 sites devoid of inferior quality microsites. The survival values were calculated from scenario 4 in Table 16.

	Caliper		
Planting site	≥ 3	≥ 4	≥ 5
A	0.867	0.960	0.995
B	0.881	0.971	0.996
C	0.880	0.972	0.996
D	0.923	0.989	0.998
E	0.901	0.985	0.998
F	0.872	0.965	0.995
G	0.897	0.983	0.998
H	0.909	0.985	0.998
Average	**0.891**	**0.976**	**0.997**
Minimum	**0.867**	**0.960**	**0.995**
Maximum	**0.923**	**0.989**	**0.998**

From decision tree analysis (Figure 5), microsites with ≥ 14.5 maximum penetration resistance and ≥ 30.9 % sand content would identify the poor quality microsites. Determining seedling quality might be fairly easy, but identifying such microsites and avoiding them during planting would be difficult. Sample processing might be required to precisely identify such sites, and relying on the planting crews to avoid such sites during planting operation would not be a preferred option. The site preparation practices might be designed to prepare microsites satisfying the maximum penetration resistance requirement, but altering the texture type might not be possible. It makes this option less attractive to follow even if it could drastically improve the average survival.

The relatively easy option would be to increase target seedling size in planting operations. Simulating the pairing of the new seedling distribution in Table 20 with the microsite distribution in Table 14 increased the average survival. Eliminating less than 3 mm caliper seedlings from the nursery supply increased survival to 81.7 % when the analysis was rerun with scenario 4 (Table 23) . Rejecting all seedlings less than 4 mm caliper from

distribution increased average survival to 87.8 %. After eliminating less than 5 mm caliper seedlings from the distribution, the average survival was 90.9 %, a significant improvement in the survival, a 10 % increase in first-year seedling survival.

Table 23: Survival calculation after rejecting seedlings below given caliper and paired with each of the 8 planting site distributions for the scenario 4 in survival matrix.

	Caliper		
Planting site	≥ 3	≥ 4	≥ 5
A	0.683	0.714	0.771
B	0.813	0.881	0.917
C	0.869	0.958	0.984
D	0.899	0.961	0.974
E	0.877	0.955	0.972
F	0.634	0.649	0.711
G	0.875	0.955	0.974
H	0.880	0.950	0.968
Average	0.817	0.878	0.909
Minimum	0.634	0.649	0.711
Maximum	0.899	0.961	0.984

Similar findings were reported from the earlier studies. South et al. (2001) found that in order to realize 90 % seedling survival the target seedling size should be greater than 5 mm. Dierauf (1982) reported that caliper size greater than 5mm caliper could increase the survival to 90 %. Radoglou and Raftoyannis (2002) found that target caliper size of 5-6 mm could give the survival percentage to about 90 %.

The increase in caliper size decreased the percentage of usable seedlings from the nursery supply, increasing per seedling costs. Eliminating seedlings 3 mm or smaller in caliper eliminated 20 % of the seedlings, which increased the per seedling cost to 5.6 ¢ from current rate of 4.0 ¢ (Table 24). Rejecting seedlings less than 4 mm caliper culled 59 % seedlings raising the cost to 10.9 cents per seedling. Eliminating seedlings less than 5 mm caliper culled 89 % seedlings, increasing per seedling cost to 40.9 ¢.

Table 24: The percentage of cull seedlings with the change in minimum caliper and the new per seedling cost. Original cost per seedling = 4.0 ¢.

Minimum caliper	Nursery supply	
(mm)	Cull seedling percentage	Per seedling cost (cents)
3	20	5.6
4	59	10.9
5	89	40.9

SUMMARY AND CONCLUSIONS

This study examined bare-root seedlings and microsite variation, and analyzed the possible options to increase the first-year seedling survival. The study was approached with simulation and field studies. The simulation study tested the feasibility of the hypothesis that survival is a function of the distributions of seedling and microsite quality. In field study, the morphological and physiological variation of bare-root seedlings and their quality distribution was computed from seedling volume. Similarly, the microsite variables were measured and the quality distribution of 8 planting sites was generated from the first-year height increment of the seedlings. The distributions were combined to calculate the predicted survival given various assumptions about survival of the combination. The options to increase the first-year survival by eliminating lower quality seedlings and the associated per seedling cost were examined.

The findings were that planting combines a heterogeneous mixture of different quality seedlings and microsites. The average caliper was 4.22 mm for the seedling sample obtained from a local nursery. The sample contained at least 31 % inferior quality seedlings and, the planting sites contained 21 % adverse microsites. The adverse microsites were with maximum penetration resistance ≥ 14.5 and sand ≥ 30.59 %. Analysis showed that the significant proportion of inferior seedlings and adverse microsites would result in lower average survival based on assumed survival matrix. The elimination of seedlings below 5 mm caliper of the nursery stock increased the survival to 90 % at the cost of 40.9 ¢ per seedling, an increase of 37 ¢ per seedling.

This study provides useful insight about how seedling and microsite variation influences first-year survival. It explores the possible options to increase the survival with the observed distribution. The information about target seedling sizes and the definition of adverse microsites could benefit planting operations. The study shows that 90 % survival

success could be achieved with the improvement in caliper size. The findings of this study are consistent with previous recommendations on optimum seedling caliper.

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APPENDIX

SIMULATION OF 400 HYPOTHETICAL PLANTINGS FROM 2O ASSUMED SEEDLING AND MICROSITE QUALITY DISTRIBUTIONS

In the simulation study, 20 hypothetical seedling and microsite quality distributions were assumed and paired in a manner that simulated 400 plantings.

A. Assumed seedling quality distribution of 20 hypothetical seedling lots.

Seedling	Seedling quality class			
Lots	a	b	c	d
1	0.25	0.25	0.25	0.25
2	0.20	0.20	0.30	0.30
3	0.10	0.10	0.30	0.50
4	0.05	0.05	0.20	0.70
5	0.05	0.05	0.70	0.20
6	0.10	0.10	0.50	0.30
7	0.05	0.05	0.45	0.45
8	0.05	0.45	0.45	0.05
9	0.10	0.50	0.30	0.10
10	0.10	0.40	0.40	0.10
11	0.00	0.50	0.50	0.00
12	0.00	0.65	0.30	0.05
13	0.05	0.60	0.30	0.05
14	0.00	1.00	0.00	0.00
15	0.00	0.00	1.00	0.00
16	0.40	0.40	0.10	0.10
17	0.50	0.50	0.00	0.00
18	0.00	0.40	0.60	0.00
19	0.10	0.40	0.40	0.10
20	0.10	0.35	0.35	0.20

B. Assumed microsite quality distribution of 20 hypothetical planting sites

Planting sites	Microsite quality class			
	a	b	c	d
1	0.25	0.25	0.25	0.25
2	0.20	0.20	0.30	0.30
3	0.10	0.10	0.30	0.50
4	0.05	0.05	0.20	0.70
5	0.05	0.05	0.70	0.20
6	0.10	0.10	0.50	0.30
7	0.05	0.05	0.45	0.45
8	0.05	0.45	0.45	0.05
9	0.10	0.50	0.30	0.10
10	0.10	0.40	0.40	0.10
11	0.00	0.50	0.50	0.00
12	0.00	0.65	0.30	0.05
13	0.05	0.60	0.30	0.05
14	0.00	1.00	0.00	0.00
15	0.00	0.00	1.00	0.00
16	0.40	0.40	0.10	0.10
17	0.50	0.50	0.00	0.00
18	0.00	0.40	0.60	0.00
19	0.10	0.40	0.40	0.10
20	0.10	0.35	0.35	0.20

C. Expected survival of 400 plantings resulted from the pairing of 20 seedling lots and planting site distributions assumed in A and B above. Each cell represents the survival from the pairing of 4 corresponding seedling and microsite quality classes for each seedling lot and planting site. Table 4 was used as the decision matrix to calculate the survival.

	Seedling lots																			
Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.50	0.55	0.65	0.70	0.70	0.65	0.70	0.60	0.55	0.58	0.63	0.59	0.56	0.50	0.75	0.35	0.25	0.65	0.58	0.59
2	0.55	0.60	0.70	0.75	0.75	0.70	0.75	0.67	0.62	0.64	0.70	0.67	0.64	0.60	0.80	0.40	0.30	0.72	0.64	0.65
3	0.65	0.70	0.80	0.85	0.85	0.80	0.85	0.81	0.76	0.77	0.85	0.84	0.80	0.80	0.90	0.50	0.40	0.86	0.77	0.78
4	0.70	0.75	0.85	0.90	0.90	0.85	0.90	0.88	0.83	0.84	0.93	0.92	0.87	0.90	0.95	0.55	0.45	0.93	0.84	0.84
5	0.70	0.75	0.85	0.90	0.90	0.85	0.90	0.88	0.83	0.84	0.93	0.92	0.87	0.90	0.95	0.55	0.45	0.93	0.84	0.84
6	0.65	0.70	0.80	0.85	0.85	0.80	0.85	0.81	0.76	0.77	0.85	0.84	0.80	0.80	0.90	0.50	0.40	0.86	0.77	0.78
7	0.70	0.75	0.85	0.90	0.90	0.85	0.90	0.88	0.83	0.84	0.93	0.92	0.87	0.90	0.95	0.55	0.45	0.93	0.84	0.84
8	0.60	0.67	0.81	0.88	0.88	0.81	0.88	0.70	0.63	0.68	0.73	0.66	0.63	0.50	0.95	0.39	0.25	0.77	0.68	0.70
9	0.55	0.62	0.76	0.83	0.83	0.76	0.83	0.63	0.56	0.61	0.65	0.58	0.56	0.40	0.90	0.34	0.20	0.70	0.61	0.64
10	0.58	0.64	0.77	0.84	0.84	0.77	0.84	0.68	0.61	0.65	0.70	0.64	0.62	0.50	0.90	0.38	0.25	0.74	0.65	0.67
11	0.63	0.70	0.85	0.93	0.93	0.85	0.93	0.73	0.65	0.70	0.75	0.68	0.65	0.50	1.00	0.40	0.25	0.80	0.70	0.73
12	0.59	0.67	0.84	0.92	0.92	0.84	0.92	0.66	0.58	0.64	0.68	0.58	0.56	0.35	1.00	0.34	0.18	0.74	0.64	0.67
13	0.56	0.64	0.80	0.87	0.87	0.80	0.87	0.63	0.56	0.62	0.65	0.56	0.54	0.35	0.95	0.33	0.18	0.71	0.62	0.65
14	0.50	0.60	0.80	0.90	0.90	0.80	0.90	0.50	0.40	0.50	0.50	0.35	0.35	0.00	1.00	0.20	0.00	0.60	0.50	0.55
15	0.75	0.80	0.90	0.95	0.95	0.90	0.95	0.95	0.90	0.90	1.00	1.00	0.95	1.00	1.00	0.60	0.50	1.00	0.90	0.90
16	0.35	0.40	0.50	0.55	0.55	0.50	0.55	0.39	0.34	0.38	0.40	0.34	0.33	0.20	0.60	0.20	0.10	0.44	0.38	0.40
17	0.25	0.30	0.40	0.45	0.45	0.40	0.45	0.25	0.20	0.25	0.25	0.18	0.18	0.00	0.50	0.10	0.00	0.30	0.25	0.28
18	0.65	0.72	0.86	0.93	0.93	0.86	0.93	0.77	0.70	0.74	0.80	0.74	0.71	0.60	1.00	0.44	0.30	0.84	0.74	0.76
19	0.58	0.64	0.77	0.84	0.84	0.77	0.84	0.68	0.61	0.65	0.70	0.64	0.62	0.50	0.90	0.38	0.25	0.74	0.65	0.67
20	0.59	0.65	0.78	0.84	0.84	0.78	0.84	0.70	0.64	0.67	0.73	0.67	0.65	0.55	0.90	0.40	0.28	0.76	0.67	0.69

D. Relative frequency table of 400 expected survival values calculated in table C above. The survival classes were with equal interval of 0.1. The frequency of survival in each class was counted and tabulated to calculate the relative frequency.

Survival class	Frequency	Relative frequency
0 - 0.1	4	0.01
0.1 - 0.2	6	0.02
0.2 - 0.3	17	0.04
0.3 - 0.4	22	0.06
0.4 - 0.5	20	0.05
0.5 - 0.6	48	0.12
0.6 - 0.7	76	0.19
0.7 - 0.8	66	0.17
0.8 - 0.9	77	0.19
0.9 - 1	55	0.14
1	9	0.02
Total	400	1

VITA

Puskar nath Khanal completed his secondary education from Bhagawati Secondary School, Arghakhanchi, Nepal, in 1995. In 1997, he graduated from Siddhanath Science Campus, Tribhuvan University, Nepal, with Intermediate Degree in Science with concentration in mathematics. He enrolled in the Institute of Forestry, Tribhuvan University and earned the undergraduate forestry degree in 2002. He worked for UNDP/GEF/SGP Nepal, between 2002 and 2007. In the fall of 2007, he enrolled in the master's program in forestry at Louisiana State University under the direction of Dr. Thomas J. Dean