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TRANSPLANT SIZE AFFECTS EARLY GROWTH OF A *PINUS TAEDA* CLONE

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Abstract. Block-plot experiments in Alabama and Georgia were examined to determine the effects of transplant size on early height growth of a tissue-cultured, Pinus taeda L clone. Ramets of clone L-3576 (miniplugs) were transplanted into a bareroot nursery at three spacings. After lifting, the transplants were sorted into three classes according to the diameter at the soil-line; 3-4.9 mm, 5-6.9 mm, 8-9.9 mm. Survival after 5 years in the field was greater than 97% at both the cutover site in Alabama and the grassland site in Georgia. At both sites, transplants with the largest diameter exhibited the greatest height and diameter growth. At year five, the difference in height between the smallest and largest class was approximately 0.5 m. This is roughly equal to a time-gain of 4 to 5 months. Stand uniformity can be improved slightly when planting large stock (when the stock range in initial diameter is 2 mm). Results from these trials suggest that early growth performance of one clone can be affected by the size of transplants at time of planting.

Keywords: stock quality, nursery, survival, clone, plantation, methyl bromide, chloropicrin, oxyfluorfen, permethrin, esfenvalerate, triadimefon, atrazine, metsulfuron methyl, sulfometuron, sethoxydim

1 Introduction

For decades, forest researchers have known that early gains in survival and growth of 1+0 bareroot pine seedlings can be achieved by planting large-diameter stock [1,2,3,4]. In fact, growth models have been developed which allow the user to vary the size of planting stock at time of planting. Models have been developed for *Pinus radiata* [5], *Pinus banksiana* [6] and *Pinus taeda* [7]. In some cases, these models indicate that that early growth gains from planting larger diameter stock may, equal (or exceed) that achieved by applying herbicides to small-diameter seedlings [8]. What is not known is if these models are also useful when the planting stock does not originate from seed and has no genetic variation (i.e. a single genotype).

Advances in somatic embryogenesis and nursery technology [9] have provided landowners in the southern United States the option of establishing clonal plantations of *Pinus taeda*. Although there are a few studies that compare the performance of seedlings with clonal stock [10,11], we are not aware of any reports that determine the effect of plant size on early growth of tissue-cultured Pinus taeda stock. When a 15 cm difference in early height is noted between seedlings and clones, few ask the question if this difference could be due to a small difference in size at planting. Typically, in most performance trials, initial height and diameter measurements are not recorded at time of planting. This can lead to confounding of initial seedling quality with treatments which sometimes leads to inappropriate conclusions [12]. In addition, it is not known if stock size has an effect on stand homogeneity. To address these deficiencies, trials were established to see if stock size (Table 1) could affect early growth and homogeneity of a tissue-cultured clone of *Pinus taeda*.

2 Materials and Methods

In March of 2004, nursery soil was fumigated with a combination of methyl bromide (439 kg/ha) and chloropicrin (9 kg/ha). Mini-plugs produced using somatic em-

Table 1: A comparison of three initial stock size classes by site for *Pinus taeda* clone L-3576. All of the transplants measured were outplanted. Values of standard errors are given in parentheses (n>255).

Variable	Cutover site			Grassland site		
Treatment	4 mm	6 mm	9 mm	4 mm	6 mm	9 mm
Average diameter (mm)	4.3 (0.5)	5.9 (0.5)	8.9 (0.5)	4.2 (0.5)	6.2 (0.5)	8.9 (0.6)
Diameter (min.–max.)	3.01–4.99	5.01–6.98	8.0–9.99	3.01–4.99	5.04–6.98	8.0–9.99
Average height (cm)	18.8 (5.1)	27.8 (2.4)	28.8 (2.7)	22.8 (4.2)	26.6 (2.4)	29.4 (2.3)
Height (min.–max.)	6–33	18–39	23–39	10–31	17–34	22–38
Average height/diameter (mm/mm)	44 (10.3)	47 (4.9)	33 (3.1)	54 (9.2)	43 (4.7)	32 (3.7)
Height/Diameter (min.–max.)	18–75	32–63	25–43	24–80	27–64	26–43
Average Bulk Index (cm^3)	3.6 (1.5)	9.9 (2.0)	22.8 (4.0)	4.2 (1.7)	10.3 (2.1)	26.3 (5.9)
Bulk Index (min.–max.)	1.0–6.8	5.5–15.9	16.0–35.0	1.0–7.3	4.7–15.6	14.4–37.8

bryogenesis tissue culture technology (Sutton et al. 2004). Mini-plug ramets of line L-3576 were manufactured in Canada by CellFor Inc. at Vancouver, BC and were shipped to Hazlehurst, Mississippi. On May 28, the mini-plugs were transplanted by hand into one bed at the PlumCreek Timberland Co. Nursery. All ramets were transplanted into 8 rows spaced 15 cm apart. Approximately one-third of the transplants were spaced 10.2 cm apart within the row. Another plot was established at within-row spacing of 3.4 cm and a third plot was spaced at 2.0 cm apart.

Herbicide applications began on June 9 when oxyfluorfen (170 g a.i./ha) was applied as a broadcast application. Similar amounts of oxyfluorfen were also applied on June, 28, July 15, July 22, August 2 and August 24. Insecticide applications began on June 17 and ended on September 17. Permethrin and esfenvalerate were applied periodically to control *Lygus linenarious* (Palisot de Beauvois). Two applications of triadimefon (350 g a.i./ha) were applied to control *Cronartium quorum f. sp. fusiforme* (Hedg. & Hunt ex Cumm.) and other fungicides were applied to lower the probability of detecting foliar diseases. Fertilization with nitrogen was conduced beginning in June and ending in September (total of 157 kg/ha applied to the crop). The amount of potassium, sulfur and calcium applied totaled 156 and 61, and 18 kg/ha, respectively.

In late summer, transplants were top-pruned in order to increase uniformity and to lower the height/diameter ratio. On January 11, 2005, the plug+1 transplants were lifted using shovels and were transported to Auburn University (where they were placed in a cooler at 3^o C). Subsamples were dried in a forced-air oven for 72 hours at 70 $^\circ$ C and dry weights of roots, stems and foliage were recorded. Prior to outplanting, diameters (at the nursery soil-line) were measured using digital calipers. The transplants were sorted into three size classes according to the diameter at groundline (i.e. position on stem between first root and first branch where the soil caused a color change). The 9 mm class contained transplants that ranged in initial diameter (DIA) from 8 to 9.99 mm while the 6 mm class ranged from 5 to 6.99 mm (Table 1). The 4 mm class ranged in diameter from 3 to 4.99 mm and plants with a diameter less than 3.0 mm were discarded. Each trial contained 12 experimental units (i.e. 4 blocks X 3 treatments) arranged in a randomized complete block design. All plots were planted at a stocking of 1075 plants per ha. The plug+1 transplants in blocks 2 and 4 were planted in a square pattern with 305 cm between trees. For these blocks, there were 100 trees per plot (i.e. 10 rows with 10 trees per row). Blocks 1 and 3 were planted in a rectangular pattern with rows 427 cm apart and trees 217 cm apart and each plot contained 105 trees (i.e.7 rows with 15 trees per row).

Heights after planting were measured from the soil line to the shoot tip. In March (cutover site) and May (grassland site), each plant was evaluated for foliar injury. Transplants free of injury symptoms were ranked as: 0 = less than 5% brown needles; 1 = 5% or more brown needles. Diameter at breast height (DBH) was recorded for years 2008 to 2010.

2.1 Cutover site This site was located near Sacapatoy in Coosa County, Alabama (GPS: N 32.980112, W 86.085375). Blocks 1, 2 and most of block 3 were planted on January 18 while the remaining plots were planted on the following day. Each planting crew planted one block. To make planting holes deeper, a gasoline powered auger was used to make holes approximately 30 cm deep. Long-handle planting shoves (TT 2-0) were used to break up the soil and to pack soil around roots. After planting, the height of each transplant was measured from the shoot tip to the groundline. Re-measurements were conducted in the winter and diameters at breast height (1.4 m) were recorded during the last three years. Herbicides were applied using a helicopter in 2005 using a tank-mix that included atrazine (3,360 g a.i./ha),

Table 2: Morphology of transplants selected for destructive sampling for *Pinus taeda* clone L-3576. None of these transplants were outplanted.

Variable	1 mm	2 mm	3 mm	4 mm	5 mm	6 mm	7 mm	8 mm	9 mm
Average diameter (mm)	1.8	2.5	3.5	4.5	5.6	6.7	7.4	8.2	9.3
Average height (cm)	14.0	14.7	20.4	26.3	27.5	27.6	28.4	28.8	28.0
Branches (#)	1	1	1	2	4	6	7	8	9
First order lateral roots (#)	7.5	9.5	11.5	10.1	11.5	13.2	11.6	14.3	15.0
Root dry weight (g)	0.14	0.22	0.76	1.03	1.56	2.42	2.55	3.98	4.64
Stem dry weight (g)	0.17	0.29	0.70	1.22	1.91	2.64	3.02	3.54	5.24
Foliage dry weight (g)	0.54	0.75	1.59	2.36	3.69	4.72	5.22	6.35	7.40
Total dry weight (g)	0.85	1.26	3.05	4.61	7.16	9.78	10.79	13.87	17.28
Root weight ratio	0.17	0.17	0.25	0.22	0.22	0.25	0.24	0.29	0.27
Seedlings sampled (#)	8	60	40	48	55	66	25	7	1

metsulfuron methyl (28 g a.i./ha) and sulfometuron (24 g ai.ha).

2.2 Grassland site This site was located at the Arrowhead seed orchard in Bleckley County, Georgia (GPS: N 32.373433 W 83.483817). Topography at this site is generally flat and the area had been disked twice prior to planting. On January 21, fresh weights were measured on 100 transplants per diameter class per replication. Weights were recorded for replication one before proceeding to the next replication. The average fresh weights were 15, 24, and 69 g, for the small, medium and large transplants. Transplants were hand-planted using long-handle TT 2-0 shovels on January 27, 2005. Heights were measured on January 26, 2006. A broadcast treatment of herbicide was applied on April 19, 2005. The treatment contained sulfometuron (105 g a.i./ha) and sethoxydim (175 g a.i./ha). Grasses between rows were mowed 3 times during the summer months.

2.3 Data Analysis Each trial utilized a randomized complete block plot design with four replicates and the trials were analyzed separately. Due to the young stand age, the analysis included only replicate and grade effects. For each tree, an inside-bark volume index was determined using a formula found suitable for *Pinus taeda* [13]. Plot means were generated and these values were analyzed using PROC GLM of the Statistical Analysis System software package [14]. Orthogonal contrasts were employed to detect linear and quadratic relationships. Stock class was treated as fixed, while replicates were treated as random effects. Differences among treatments were declared significant at the alpha = 0.1 level. A transplant stress index (TSI) was determined for each trial in the manner described previously [15]. TSI is equal to the slope of the linear relationship between shoot height at the beginning of the growth period and height increment. First-year height growth was generated for each surviving tree and these values were regressed against initial height to obtain a TSI value for each plot. Each regression included more than 90 transplants. A negative TSI indicates transplants have undergone transplant shock and the more negative the value, the greater the intensity of transplant stress. Stand uniformity was examined by calculating a coefficient of variation (standard deviation/mean) for height and DBH.

RCDlob is a growth and yield model that was developed using seedling data for *Pinus taeda* [7]. It allows the user to estimate the growth of seedlings that vary in initial size (i.e. root-collar diameter). We wanted to know if this model could also approximate the growth gains observed for planting larger ramets in a monoclonal plantation. Therefore, we conducted a simulation using a planting density of 1075 plants per ha and a standard site preparation scenario. We then compared the observed 5^{th} year values with the RCDlob projections from planting 4 mm, and 9 mm stock.

3 Results and Discussion

The size of transplants was similar at both planting locations. Although the 9-mm transplants had a greater bulk index (i.e. diameter X diameter X height) and were slightly taller than the 6-mm class, they had lower height/diameter ratios (Table 1). Destructive sampling indicated that the 8-mm class was heavier and tended to have a higher root weight ratio (i.e. root dry weight/total plant dry weight) than transplants with smaller diameters (Table 2).

3.1 Survival Five years after planting, survival on both sites was excellent on both sites. Survival at the cutover and grassland sites averaged 98.7% and 98.6 % respectively. As a result, there was no effect of stock size on survival (Table 3). The high survival might be attributed to planting roots in deep holes (in this case,

Table 3: Probability of a greater F-statistic for survival (year 5), foliar damage (Damage), diameter at breast height at year 5 (DBH), and volume per ha at year 5 (Volume) of a *Pinus taeda* clone as affected by stock size at planting. Numbers in brackets represent L.S.D. values (α =0.05).

Site		d.f.	Survival	Damage	DBH	Volume
Cutover	Replication	3	0.3495	0.3267	0.5108	0.4393
	Size	2	0.3199	0.0467	0.1542	0.1356
	Linear	-1	0.5708	0.1527	0.0734	0.0656
	Quadratic	-1	0.1713	0.0301	0.5090	0.4601
	Error	6	[2.4]	[26]	[10.9]	[7.0]
Grassland	Replication	3	0.3910	0.4697	0.0575	0.2112
	Size	2	0.5057	0.0002	0.0069	0.0148
	Linear	-1	0.2818	0.0356	0.0024	0.0055
	Quadratic	-1	0.7278	0.0001	0.6904	0.4866
	Error	6	[3.0]	[10]	[5.3]	[3.7]

made with the use of shovels or augers). The top of the foam miniplug was typically planted about 7 cm below the soil surface. In addition, when compared to seedlings (archived data from a different nursery and different year), it appears the transplants might have larger diameters for a given height (Figure 1). It is possible diameter gain is due to the head-start transplants receive from additional time spent in greenhouse culture. Although a similar pattern in heights and diameters have been observed for *Pinus radiata* cuttings [16], more research would be needed to determine if a trend of lower height/diameter ratios is repeatable for clonal transplants from other *Pinus taeda* nurseries.

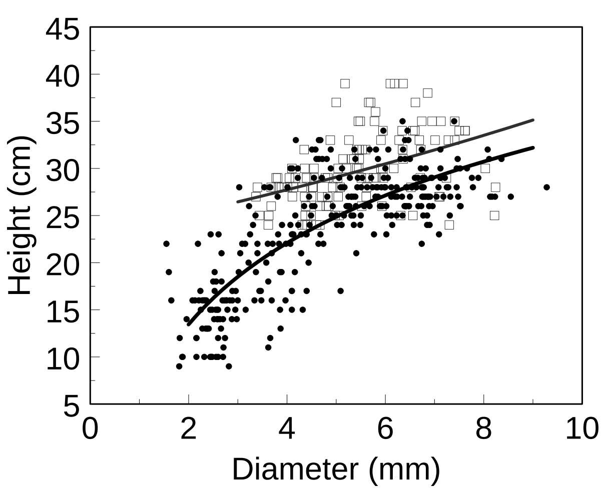

Figure 1: A comparison of nursery height and nursery diameter for bareroot *Pinus taeda* seedlings from a nursery in Alabama (top line; open squares) and for transplants of clone L-3576 from a nursery in Mississippi (bottom line; solid dots).

3.2 Foliar injury *Pinus taeda* may turn a "nitrogen-deficient" color after exposure to freezing weather [17]. Brown foliage can be a sign of freeze injury and foliar injury was observed at the cutover site in early February. A few days after planting, freezing temperatures (as low as -8 ^{o}C) occurred on the 24th, 25th and 26th of January. Foliage assessed in March indicated that brown needles occurred on a third of the trees. Foliar injury was also noted on about a third of the small stock at the grassland site. At that location, freezing temperatures (e.g. -1 ^{o}C) occurred just a few days after planting (i.e. January 28, 29th, and 30th). At both sites, foliar symptoms were greater on stock with a DIA that was smaller than 5 mm (Table 4). At both locations, the injury had a quadratic relationship with size (Table 5). This observation is supported by others who reported that freeze injury is negatively related to RCD [18]. The injury was ephemeral and trees at both sites recovered quickly.

3.3 Transplant Stress Index (TSI) Negative TSI indicate transplanting stress while positive values indicate little or no stress. Negative TSI values are the norm for the first year after planting *Pinus taeda* seedlings [15, 19]. As expected, first year TSI values for the transplants (Table 4) were negative at both the cutover (TSI = -1.0) and grassland sites (TSI = -0.2). Not only were TSI values lower at the cutover site, but negative values were observed there for three years. In contrast, average TSI values turned positive by the second year at the grassland site. This suggests that transplant stress was greater at the cutover site.

Table 4: Effect of initial stock size on survival, height, diameter at breast height (DBH), foliar damage, and Transplant Stress Index (TSI) of *Pinus taeda* clone L-3576 in Alabama (Cutover) and Georgia (Grassland). Except for the 9 mm class for year 5 height, all means are for four replications.

Site	Class	Variable	After planting	Year 1	Year 2	Year 3	Year 4	Year 5
Cutover	4 mm	Height (cm)	20	48	125	220	351	513
	6 mm	Height (cm)	21	56	141	243	377	550
	9 mm	Height (cm)	22	61	152	255	395	559
	4 mm	DBH (mm)				17	44	72
	6 mm	DBH (mm)				20	50	79
	9 mm	DBH (mm)				22	53	82
	4 mm	Volume (m^3/ha)						16
	6 mm	Volume (m^3/ha)						21
	9 mm	Volume (m^3/ha)						23
	4 mm	Damage (%)	52					
	6 mm	Damage (%)	31					
	9 mm	Damage (%)	18					
	4 mm	TSI		-1.29	-0.11	-0.1	-0.12	0.03
	6 mm	TSI		-0.86	-0.17	-0.31	0.08	0.04
	9 mm	TSI		-0.95	0.11	-0.39	0.06	0.06
Grassland	4 mm	Height (cm)	16	68	164	295	422	529
	6 mm	Height (cm)	20	77	177	310	459	593
	9 mm	Height (cm)	22	96	209	350	476	646
	4 mm	DBH (mm)				35	65	106
	6 mm	DBH (mm)				37	67	109
	9 mm	DBH (mm)				46	75	116
	4 mm	Volume (m^3/ha)						19
	6 mm	Volume (m^3/ha)						22
	9 mm	Volume (m^3/ha)						25
	4 mm	Damage (%)	38					
	6 mm	Damage (%)	7					
	9 mm	Damage (%)	1					
	4 mm	TSI		-0.15	0.57	0.28	0.06	1.34
	6 mm	TSI		-0.42	0.45	0.27	0.13	0.65
	9 mm	TSI		-0.32	0.07	0.01	-0.23	0.46

Regardless of year, we did not detect a significant treatment effect on TSI values at the cutover site. However, stock size at the grassland site apparently affected TSI values during the second, third and fourth years (Table 5). The significant linear effect suggests the bulker and heavier transplants exhibited lower TSI values when compared to the smaller transplants.

3.4 Height and diameter A derecho event occurred at the Alabama site on May 3, 2009. A derecho is a widespread and long-lived straight line wind storm associated with a fast moving squall line. Central Alabama experienced widespread winds of 80 to 100 kph and some locations received maximum winds of 110 to 130 kph. A few thousand trees may have been blown down across Central Alabama. At the Alabama trial, perhaps 5% of the trees had broken tops (i.e. height growth less than 30 cm for the year). Breakage was related to block location. There was less than 1% breakage in block #3 but in block #2, the 9 mm plot had 28% breakage. For this reason, this plot was dropped in the analysis for 5^{th} year heights. More height growth occurred at the grassland site (average height was 584 cm) in Georgia when compared to the cutover site in Alabama (average height was 539 cm). The soil at the Georgia location had fewer rocks, more topsoil, and less hardwood competition.

Prior to the derecho event, the effect of stock size on early height growth was similar for both sites. After four years, the difference in height between the smallest and largest class ranged from 51 cm on the cutover site to 54 cm on the grassland site (Table 4). Treatment rankings were the same for both sites and treatment was significant for both sites (Table 6). For 5^{th} year heights, the absolute difference between sites increased and the

Table 5: Probability of a greater F-statistic for transplant stress index (TSI) of *P. taeda* clone L-3576 as affected by stock size at planting. Numbers in brackets represent L.S.D. values (α =0.05).

		Prob>F									
		Cutover					Grassland				
	D.f.	Year 1	Year 2	Year 3	Year 4	Year 5	Year 1	Year 2	Year 3	Year 4	Year 5
Replication	3	0.6984	0.7533	0.0224	0.6292	0.6285	0.9937	0.4782	0.3357	0.3971	0.5602
Size	2	0.2488	0.7313	0.6046	0.7310	0.9503	0.4899	0.0466	0.0545	0.0178	0.2784
Linear	(1)	0.1762	0.6142	0.3387	0.5027	0.7918	0.3293	0.0239	0.0409	0.0314	0.1311
Quadratic	(1)	0.3171	0.5616	0.9050	0.7096	0.8759	0.5126	0.2451	0.1296	0.0231	0.7273
Error	6	[0.6]	[1.0]	[0.7]	[0.7]	[0.2]	[1.1]	[0.4]	[0.2]	[0.2]	[1.3]

Table 6: Probability of a greater F-statistic for height of a *Pinus taeda* clone L-3576 as affected by stock size at planting. Numbers in brackets represent L.S.D. values ($\alpha = 0.05$).

		D.f.	Prob>F					
			After planting	Year 1	Year 2	Year 3	Year 4	Year 5
Cutover	Replication	3	0.3725	0.5427	0.9015	0.8556	0.6238	0.2040
	Size	2	0.6905	0.0063	0.0700	0.1215	0.1236	0.4583
	Linear	(1)	0.4145	0.0024	0.0287	0.0559	0.0529	0.3059
	Quadratic	(1)	0.8917	0.3017	0.5701	0.4983	0.6308	0.5709
	Error	5-6	[6]	[6]	[23]	[36]	[44]	[92]
Grassland	Replication	3	0.3265	0.1008	0.5440	0.2151	0.0222	0.3213
	Size	2	0.0007	0.0001	0.0052	0.0075	0.0104	0.0273
	Linear	(1)	0.0068	0.0001	0.0017	0.0026	0.0021	0.0118
	Quadratic	(1)	0.0005	0.9136	0.8911	0.7457	08586	0.3189
	Error	6	[1.1]	[5]	[21]	[27]	[21]	[73]

difference between the smallest and largest class was 46 cm on the cutover site and 117 cm on the grassland site. The less than expected height growth at the cutover site might be a result of wind damage experienced in May. Due to an increase in plot variability, the treatment effect was no longer significant at the cutover site.

At year five, the difference in fifth-year diameter between the smallest and largest class was similar for both sites (1 to 1.1 cm). This difference was significant at both sites (Table 3). Since survival was high at both sites, the difference in stand volume was driven by the difference in DBH. Planting stock that averaged 5 mm larger in diameter resulted in greater than 30% volume gain at both sites (Table 3). Of course, as the stand ages, the absolute gain might increase as the percentage gain declines [20, 21].

3.5 Time Gain In addition to absolute gains, an estimate of the time-gain [22] was made using annual height measurements. By plotting height over time and using linear equations, a "hypothetical" number of days required to reach a height of 5 m was calculated (assuming growth rate is constant throughout the year). When 6 mm stock was planted on the cutover site, a height of 5 m was reached 3 months sooner than for the smaller stock (i.e. 4 mm diameters). Likewise, on the grassland site the time gain for this comparison was estimated at 4 months. Assuming a plantation is harvested when the current annual increment (CAI) is 16 m^3/ha, then three months of additional growth would translate into a gain in volume of 4 m^3/ha.

3.6 No genetic confounding Height growth of pines can be affected by differences in physiology, morphology, environment and genotype. Since a single genotype (L-3576) was used in this study, growth and uniformity differences among plots were solely due to differences in environment (e.g. site), or were due to differences among transplant classes in physiology or morphology (e.g. size). In previous studies that reported better growth with larger seedlings [2, 19] or cuttings [16, 23], the grading process (prior to planting) might have introduced some confounding of genotype with seedling grade. In contrast, the conclusions from this study are free of any potential confounding with genotype. This study supports the conclusions of seedbed density studies that plant size can affect subsequent growth. In fact, some growth equations are based on the idea that growth is a function of tree size [24]. The realized gain from planting larger stock (i.e. 6 mm stock vs. 4 mm stock) might be similar to realized gains from planting certain clones (Figure 2).

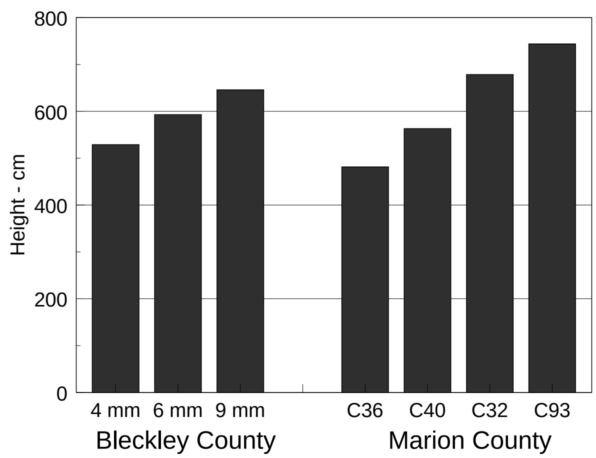

Figure 2: A comparison of height gains (age 5 years) from planting larger *Pinus taeda* transplants (Bleckley County, Georgia; clone L-3576) with planting four clones of *Pinus taeda* (Marion County, Georgia). The absolute gain from planting transplants that were 2 mm larger in diameter (ie. 6 mm vs. 4 mm) was approximately the same as that achieved from planting clone C40 vs. clone C36 [11].

3.7 Culling standards At some nurseries, an attempt is made to cull stock prior to shipping trees to outplanting sites. Nursery managers give packers morphological specifications to use to identify culls. Due to time constraints, only a few morphological standards are used during the culling process. Typically, seedlings that are too small to plant easily are culled as well as those with obvious signs of disease. In some cases, large stock is considered to be culls because tree planters might not plant them properly [23].

For clonally propagated stock, morphological culling standards are either based on intuition or data from outplanting studies [16, 23, 25]. When field performance trials are lacking, many nursery managers use intuition to set culling limits. For example, stock with diameters greater than 10 mm might be culled even though they survive and grow better than stock with 4 to 6 mm diameters [23]. On the other end of the spectrum, we did not test transplants with diameters less than 3 mm because they have smaller roots and lower root-weight ratios (Table 2). We assumed they would have lower survival potential. However, in other trials, some nurseries have shipped ramets with diameters as small as 1 mm. In situations where both the demand and price for clonal stock is high, there may be an incentive to lower culling standards and ship ramets with diameters in the 1 and 2 mm range (Table 2).

3.8 RCDlob The 5^{th}-year RCDlob simulations produced average heights of 518 and 579 cm for the 4 mm and 9 mm plants, respectively. The RCDlob simulation for height gain (i.e. 61 cm) was in between the realized values for the cutover site (46 cm) and grassland site (117 cm). The RCDlob estimate for average quadratic DBH at year six was 72 mm for the 4-mm stock and 75 mm for 9-mm stock. For the cutover site, the respective 5-year DBH values were 73 mm and 83 mm which are close to the simulated values. The results suggest the site index for the cutover site might be similar to the RCDlob site index (i.e. simulated height of tallest 20 trees at age 25 years = 26 m). In contrast, the RCDlob simulations underestimated realized height and DBH gains at the grassland site.

3.9 Stand uniformity In this trial, stand uniformity was affected by the environment and by transplant size. The environment was more uniform at the cutover site than for the grassland site (Figure 3 and 4). Greater uniformity at the grassland site meant that differences among means were easier to detect (statistically). The CV values reported for the sites above are more uniform than those reported for three clones planted in North Carolina [26].

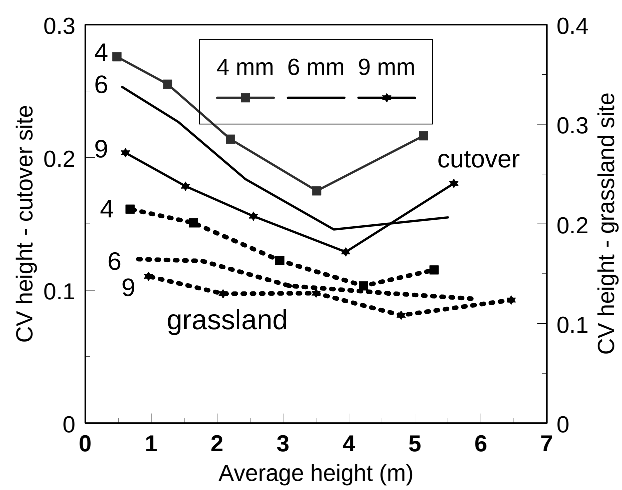

Figure 3: Uniformity in stand height is affected by size of planting stock (ie. 4 mm, 6 mm, 9 mm) and by height of stand at time of measurement. Each point represents the coefficient of variation (CV) of more than 332 ramets of *Pinus taeda* L-3576.

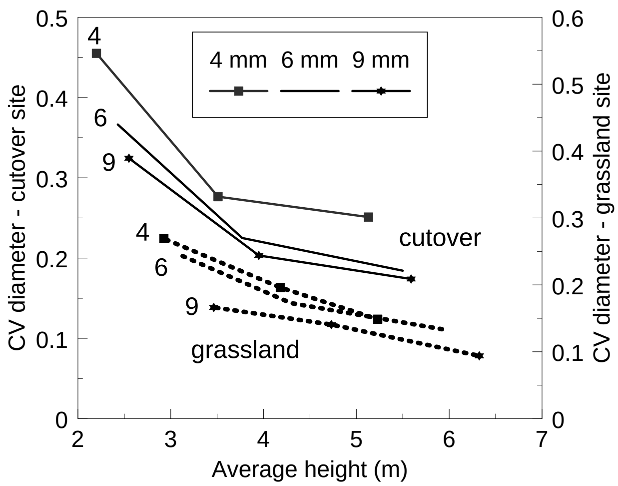

Figure 4: Uniformity in stand diameter at breast height is affected by size of planting stock (ie. 4 mm, 6 mm, 9 mm) and by height of stand at time of measurement. Each point represents the coefficient of variation (CV) of more than 332 ramets of *Pinus taeda* L-3576.

The CV in height (Figure 3) and CV in diameter (Figure 4) generally decreased as average height of the stand increased. An exception was noted at the cutover site where the CV for height increased during the fifth growing season. It is likely this increase was related to stem breakage as a result of the derecho event. Other researchers have reported a reduction in CV (for both height and diameter) as the stand increases in size [25, 27, 28].

An unexpected finding was that transplant size at planting had an effect on stand uniformity. At both sites, the larger transplants exhibited more uniformity than the smaller, 4-mm class (Figures 3 and 4). The gain in uniformity from planting 9-mm transplants in a mono-clonal plantation was considerable, especially when compared to reported gains in uniformity from planting a single clone instead of a mixture of clones. For height, Sharma et al. [27] reported a CV (DBH at age 12 yr) of 0.142 of a clonal mixture (i.e. 10 clones) compared with a CV of 0.126 for a mono-clonal plantation. This difference (0.016) is less than the 0.055 and 0.077 differences observed between the 4-mm class and 9-mm classes (age 5 years) at the cutover site and grassland sites, respectively. This suggests that transplant size at planting can affect stand homogeneity.

Economically, variability in DBH is minimally important when stands are harvested for biomass or for pulpwood. In these cases, additional volume growth is the primary justification for establishing mono-clonal plantations. In contrast, homogeneity can affect net present value (NPV) when landowners harvest sawtimber. In such cases, uniformity can affect stand value (when stands contain the same amount of volume at harvest). In situations where greater uniformity decreases the amount of pulpwood and increases the amount of sawtimber, then the NPV will be increased. In contrast, increased uniformity might lower NPV in situations where the proportion of sawtimber is decreased due to a proportional increase in pulpwood [29, 30, 31, 32]. Therefore, greater uniformity does not always result in more profit. Not only is it important to select the correct clone, but it may be wise to select a nursery that produces homogeneous ramets. Establishing a mono-clonal plantation with heterogeneous ramets might result in a non-uniform stand [26].

4 Conclusions

Plant size is important for good field growth of ramets propagated with either rooted cuttings [23] or tissue culture. From the trials reported here, transplants with diameters of 8 to 9.99 mm and heights of 22 to 39 cm performed better than stock with diameters less than 5 mm. An increase in initial diameter of 5 mm (i.e. 4.3 vs 9.3 mm) increased 5^{th} year height by 46 cm to 117 cm. An increase in diameter of just 2 mm might increase average height by 20 cm to 60 cm. On some productive sites, planting uniformly large transplants could improve homogeneity and could increase yields by 3 to 4 m^3/ha (at age 5 years). This might result in a gain in stand development of 4 to 5 months.

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