Review Paper

Effect of planting depth on growth of open-rooted *Pinus elliottii* and *Pinus taeda* seedlings in the United States

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SYNOPSIS

Three studies in the Coastal Plain of Georgia were remeasured 7 or 8 years after planting to determine the effects of planting depth on field performance of open-rooted seedlings [root-collar diameter (RCD) ≥ 5 mm]. Average planting depth (i.e. shoot height before planting minus shoot height above ground after planting) for machine planted *P. elliottii* was 14 cm while hand-planted *P. taeda* seedlings averaged 9-11 cm deep. *P. taeda* showed no adverse effects on growth when planting seedlings up to 15 cm deep. Data for machine planted *P. elliottii* indicated that seedlings were planted 9 mm deeper on double-beds than on single-beds. Small-diameter pine seedlings (< 5 mm RCD) were not planted as deeply as seedlings with large diameters (RCD ≥ 5 mm). For P. e*lliottii* planted on double-beds, seedlings planted more than 15 cm deep had slightly smaller diameters at breast height than seedlings planted 10 cm deep. Although most tree planting guides recommend planting seedlings 7,5 cm deep or less, many company plantations have been established by planting at greater depths.

Keywords: *Pinus elliottii*, *Pinus taeda*, survival, seedling quality, planting quality reforestation

INTRODUCTION

In the United States, there are two schools of thought regarding the desired planting depth of open-rooted *P. elliottii* and *P. taeda* seedlings. One school favours keeping the taproot straight and placing the root-collar 0 to 7,5 cm below the soil surface on all sites. Some from this school say seedlings are planted correctly when they are "tightly planted at root collar depth with no L or J roots" (Shiver *et al*., 1990). Tree planters from this school will prune roots to make it easier to plant with minimal root distortion. The other school favours planting the root-collar 13 to 20 cm below the soil-line on well drained sites to increase the probability of survival. This school is more concerned with making a deep planting hole, keeping roots intact and placing the roots near the bottom of the hole than it is with keeping the taproot straight. This method results in the root-collar being planted 10 to 20 cm below the soil surface with some degree of L- and J-roots. Although much is written about the dangers of "deep" planting and J-roots, most information published to date shows no adverse effects of J-rooting (per se) either on survival or early height growth of open-rooted seedlings (South, 1999). In spite of this, some say planting seedlings deep will "increase mortality" since many taproots will have U-, J- or L- roots.

Some researchers take great care to plant the root-collar at the soil surface (Shriver *et al*., *1990*) since most tree planting guides in the southern United States recommend planting *P. taeda* with the root-collar 0 to 7,5 cm below the soil surface. One company published tree planting guide says to plant the root collar "slightly more than one inch below the soil surface." Moorhead (1988) reports that *P. elliottii* and *P. taeda* seedlings "can be planted with up to two to three inches above the root collar, provided the planting hole is deep enough to avoid root deformation." This means that when the planting hole is 18 cm deep and the taproot is 18 cm long, the root-collar should be planted at the ground-line (and not 10 cm below ground-line). However, taking great care to ensure the taproot is straight can increase planting costs up to 400% (Harrington and Howell, 1998).

Several researchers have tested the effects of planting depth on survival of pines (Slocum, 1951; Smith, 1954; Wakeley, 1954; Slocum and Maki, 1956; Malac and Johnson, 1957; Switzer, 1960; Shoulders, 1962; McGee and Hatcher, 1963; Swearingen, 1963; Ursic, 1963; Sutton, 1966; Donald, 1970; Dierauf, 1984; Bilan, 1987; Blake and South, 1991). In most cases, deeper planting increases survival of *P. elliottii* and *P. taeda* (**Figure 1**). On sandy soils, survival is increased even when the entire stem (except for the terminal) is buried. However, on poorly drained agricultural soils, planting seedlings deep on non-bedded areas can reduce survival (Switzer, 1960). Likewise, planting seedlings in shallow holes (10 to 15 cm) can result in low survival since the root system is unable to absorb enough moisture during summer droughts (South, 1999; Harrington, 2000). Therefore, tree planters should avoid planting open-rooted pine seedlings in shallow planting holes and should not plant the root-collar above the soil (Slocum and Maki, 1956; Ursic, 1963; Smith, 1954; Shiver *et al*., 1990; Schwan, 1994).

For *P. elliottii* and *P. taeda*, deep planting also tends to increase height growth (Slocum, 1951; Slocum and Maki, 1956; Koshi, 1960; McGee and Hatcher, 1963; Swearingen, 1963) but some have reported a decrease in early growth (Switzer, 1960; Ursic, 1963; Bilan, 1987). Dierauf (1984) showed that planting depth had no affect on early height growth of *P. taeda*. A summary of the literature from the United States is provided in **Table 1** and **Figure 2**. However, none of these studies examined growth past age 5 and only two studies actually reported the absolute planting depth (Slocum and Maki, 1956; Dierauf, 1984). Reporting that seedlings were planted with half of the stem below ground (**Table 1**) is not very scientific since, depending on shoot height, this means the root-collar might be 7 or 23 cm below the soil surface. In one study, "deep planting" was defined only as "root collar significantly below ground line" (Shiver *et al*., 1990).

There are several advantages of planting seedlings with the root-collar 13 to 20 cm below groundlevel. The main advantage is that survival can be improved in situations where overall survival is less than 90% (**Figure 1**). This can occur when seedlings are planted on sandy sites or on sites where moisture is limited. Since managers cannot predict if droughts will occur after planting, seedlings that are planted deep will tolerate droughts better than those planted with the root-collar near the surface. In some cases, the productivity of tree planters is increased since additional time required to ensure the taproot is straight could be eliminated (Harrington and Howell, 1998). In more polar climates, injury from frost heaving could be reduced by deep planting (Schwan, 1994).

The belief that pine seedlings should not be planted deep on poorly drained soils originates from two old-field sites in Mississippi (Switzer, 1960). We wanted to know if these findings could be repeated on somewhat poorly drained cutover sites that had been bedded prior to planting. Therefore, this paper presents data on the effects of planting depth on the performance of 7- and 8-year-old pines. These data are included as part of a summary of planting-depth literature in the southern United States.

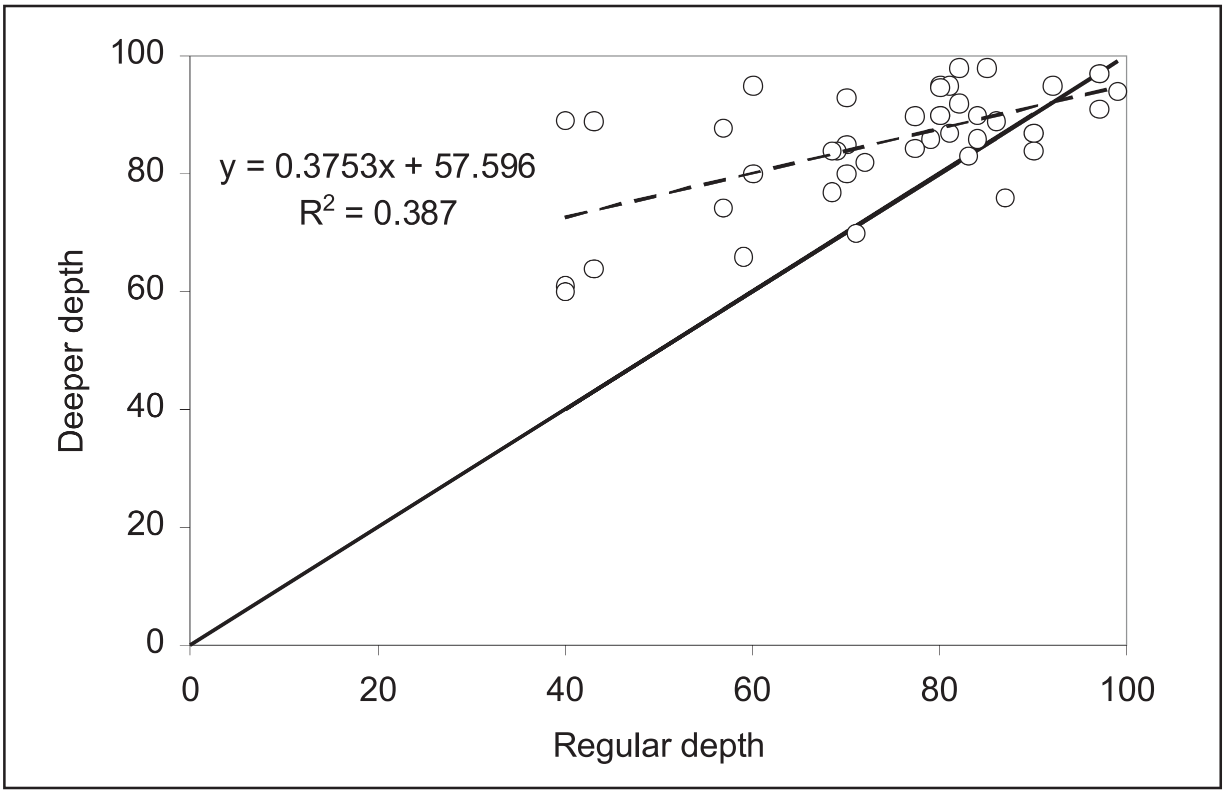

FIGURE 1. Comparison in survival between regular planting depth (root-collar just below ground) and deeper planted P. taeda or P. elliottii pine seedlings on well-drained sites. The dashed line represents the regression equation (n = 43). The solid diagonal line represents equal survival of the two treatments. Points above the solid line represent cases where deeper planting increased survival.

MATERIALS AND METHODS

Three seedling-size studies were located on somewhat poorly drained soils throughout the southeastern Coastal Plain. *P. elliottii* seedlings were machine-planted at a site near Homerville, Georgia (31º 03' N, 82º 44'W), while *P. taeda* was hand-planted on a site in Tattnall County, Georgia (35º 51' N, 82º 03'W) and in Hampton, County South Carolina (32º 36' N, 81º 20'W). At Homerville, the area was site prepared using a bedding plow (i.e. single bed) in June 1991 and then in early October, beds on half of the plots were reformed with a second bedding pass (i.e. double bed). Additional information about silvicultural treatments and site characteristics have been previously reported (South and Mitchell, 1999; South *et al*., 2001). Prior to planting, root-collar diameter (RCD) and total seedling height above the root-collar (root-collar to the tip of the terminal leader) (HT) were measured for all seedlings. Experienced company crews were not given instructions by researchers on how to plant seedlings. Immediately after planting, ground-line diameter (GLD) and total seedling height above the ground-line (ground-line to the tip of the terminal leader) (SHAG) were measured for all planted seedlings. Planting depth (PD) was calculated by subtracting SHAG from HT (Slocum and Maki, 1956).

DBH and total tree height were measured in March and April of 2000. Individual tree volume was estimated using an equation developed by Van Deusen *et al*. (1981). DBH, total tree height, and individual tree volume were analyzed by Proc GLM of SAS (SAS Institute, Inc., 1989). Due to differences in treatments and study design between the Homerville site and the other two sites, analyses for planting depth were slightly different. At each site, 4 planting depth categories were determined by dividing the distribution into approximately equal sample sizes. Since small seedlings are not planted as deeply as large-diameter seedlings, only seedlings with RCD > 5 mm were used in the statistical analyses.

P. elliottii

Seedlings were planted by an operational crew on 16 October, 1991. The average planting depth for the machine planted seedlings was 14,3 cm (**Figure 3**). Individual trees within the selected RCD classes were placed into 4 planting depth categories: 1 to 12,4 cm, 12,5 to 14,9 cm, 15 to 17,4 cm, and 17,5 to 38 cm. RCDs in this study ranged from a minimum of 2,0 mm to a maximum of 13,0 mm.

A preliminary split-split plot analysis was conducted to determine if planting depth was confounded with bedding treatment (main-plot) or herbicide treatment (split-plot). This analysis determined that planting depth was significantly (p=0,036) deeper on double-beds (**Figure 4**).

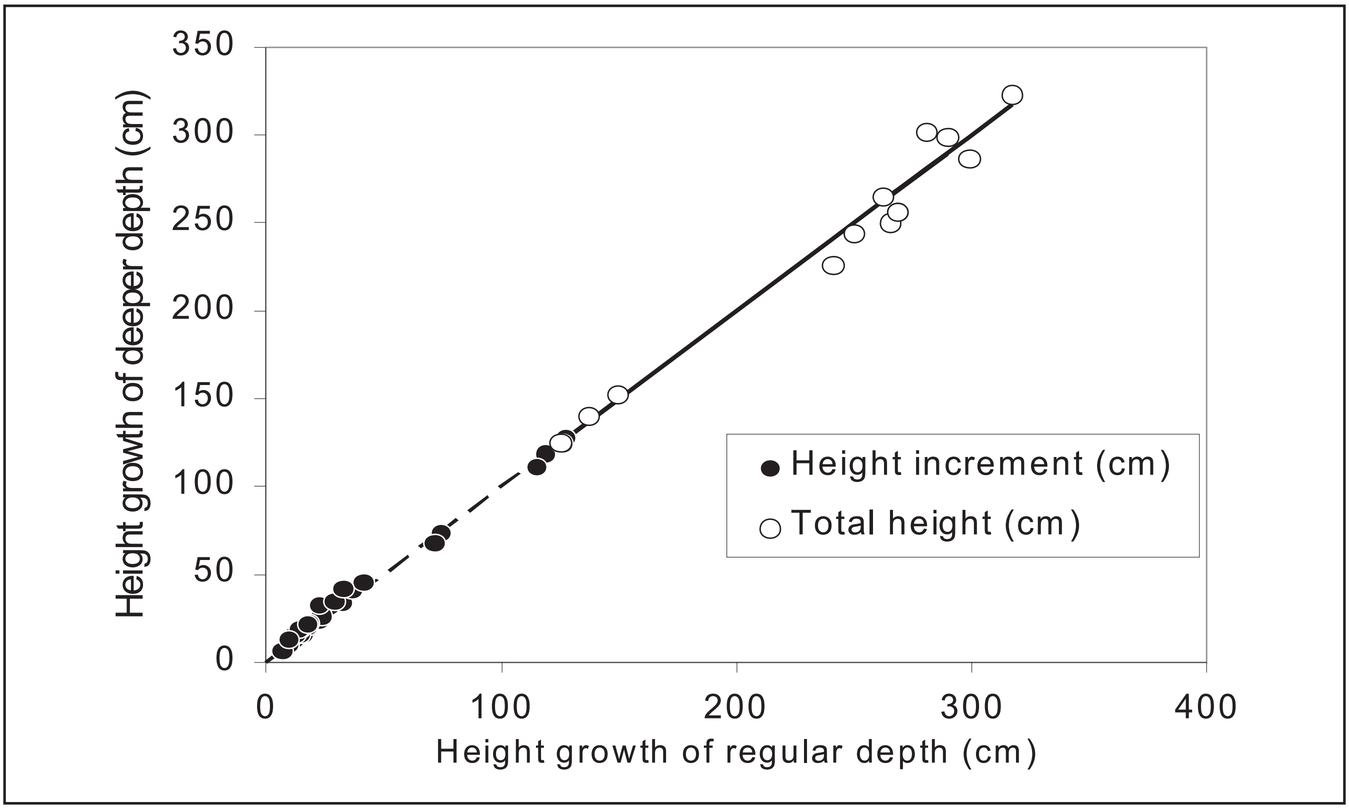

FIGURE 2. Comparison of growth between regular planting depth (root-collar just below ground) and deeper planted P. taeda or P. elliottii seedlings on well-drained sites. The lines represent equal growth of the two treatments. Points above the line represent cases where deeper planting increased growth. Solid points (n = 34) represent height increment while open points (n = 13) represent total height. Citations are listed in ***Table 1****.*

*TABLE 1. Effect of deeper planting depth (relative to planting seedlings with the root-collar close to the ground-line) on the gain in annual height growth (HG) or gain in total height (TH) for various ages after planting. * = significant at the 0,05 alpha level.*

Year	Species	Planting depth	Gain in HG or TH (cm)	Variable	Years after planting	Reference
1950	*P. taeda*	¼ stem	1,78	HG	1	Slocum 1951
1952	*P. taeda*	¼ stem	4,62	HG	1	Slocum and Maki 1956
1953	*P. taeda*	¼ stem	5,61	HG	2	Slocum and Maki 1956
1950	*P. taeda*	½ stem	3,05	HG	1	Slocum 1951
1952	*P. taeda*	½ stem	1,78	HG	1	Slocum and Maki 1956
1953	*P. taeda*	½ stem	1,57	HG	2	Slocum and Maki 1956
1957	*P. elliottii*	½ stem	2,03	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	½ stem	0,76	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	½ stem	0,51	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	½ stem	1,02	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	½ stem	0,25	HG	1	McGee and Hatcher 1957
1959	*P. taeda*	½ stem	5,84*	HG	1	Bilan 1987
1960	*P. taeda*	½ stem	-0,25	HG	2	Bilan 1987
1961	*P. taeda*	½ stem	0,25	HG	3	Bilan 1987
1961	*P. elliottii*	½ stem	0,06	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	½ stem	21*	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	½ stem	-12*	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	½ stem	9	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	½ stem	-6	TH	5	McGee and Hatcher 1963
1962	*P. taeda*	½ stem	0,51	HG	4	Bilan 1987
1952	*P. taeda*	¾ stem	4,78	HG	1	Slocum and Maki 1956
1953	*P. taeda*	¾ stem	5,31	HG	2	Slocum and Maki 1956
1953	*P. taeda*	1/3 stem	1,78	HG	1	Slocum and Maki 1956
1953	*P. taeda*	1/3 stem	1,52	HG	1	Slocum and Maki 1956
1953	*P. taeda*	2/3 stem	0,76	HG	1	Slocum and Maki 1956
1953	*P. taeda*	2/3 stem	4,06*	HG	1	Slocum and Maki 1956
1982	*P. taeda*	3,15 cm	0	TH	3	Dierauf 1984
1982	*P. taeda*	3,15 cm	3	TH	3	Dierauf 1984
1982	*P. taeda*	3,15 cm	3	TH	3	Dierauf 1984
1953	*P. taeda*	To terminal	2,79*	HG	1	Slocum and Maki 1956
1953	*P. taeda*	To terminal	3,30*	HG	1	Slocum and Maki 1956
1957	*P. elliottii*	To terminal	10,16	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	To terminal	5,08	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	To terminal	4,06	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	To terminal	5,33	HG	1	McGee and Hatcher 1957
1957	*P. elliottii*	To terminal	3,3	HG	1	McGee and Hatcher 1957
1961	*P. elliottii*	To terminal	4,06*	HG	1	Swearingen 1963
1961	*P. elliottii*	To terminal	4,57*	HG	2	Swearingen 1963
1961	*P. elliottii*	To terminal	-12*	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	To terminal	3	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	To terminal	-15*	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	To terminal	-12*	TH	5	McGee and Hatcher 1963
1961	*P. elliottii*	To terminal	-15*	TH	5	McGee and Hatcher 1963
1959	*P. taeda*	Up to 4-mm from terminal bud	9,40*	HG	1	Bilan 1987
1960	*P. taeda*	Up to 4-mm from terminal bud	-3,05*	HG	2	Bilan 1987
1961	*P. taeda*	Up to 4-mm from terminal bud	-3,56*	HG	3	Bilan 1987
1962	*P. taeda*	Up to 4-mm from terminal bud	-1,02	HG	4	Bilan 1987
Poorly drained, old-field sites						
1959	*P. taeda*	½ stem	-9	TH	1	Switzer 1960
1959	*P. taeda*	To terminal	-23*	TH	1	Switzer 1960

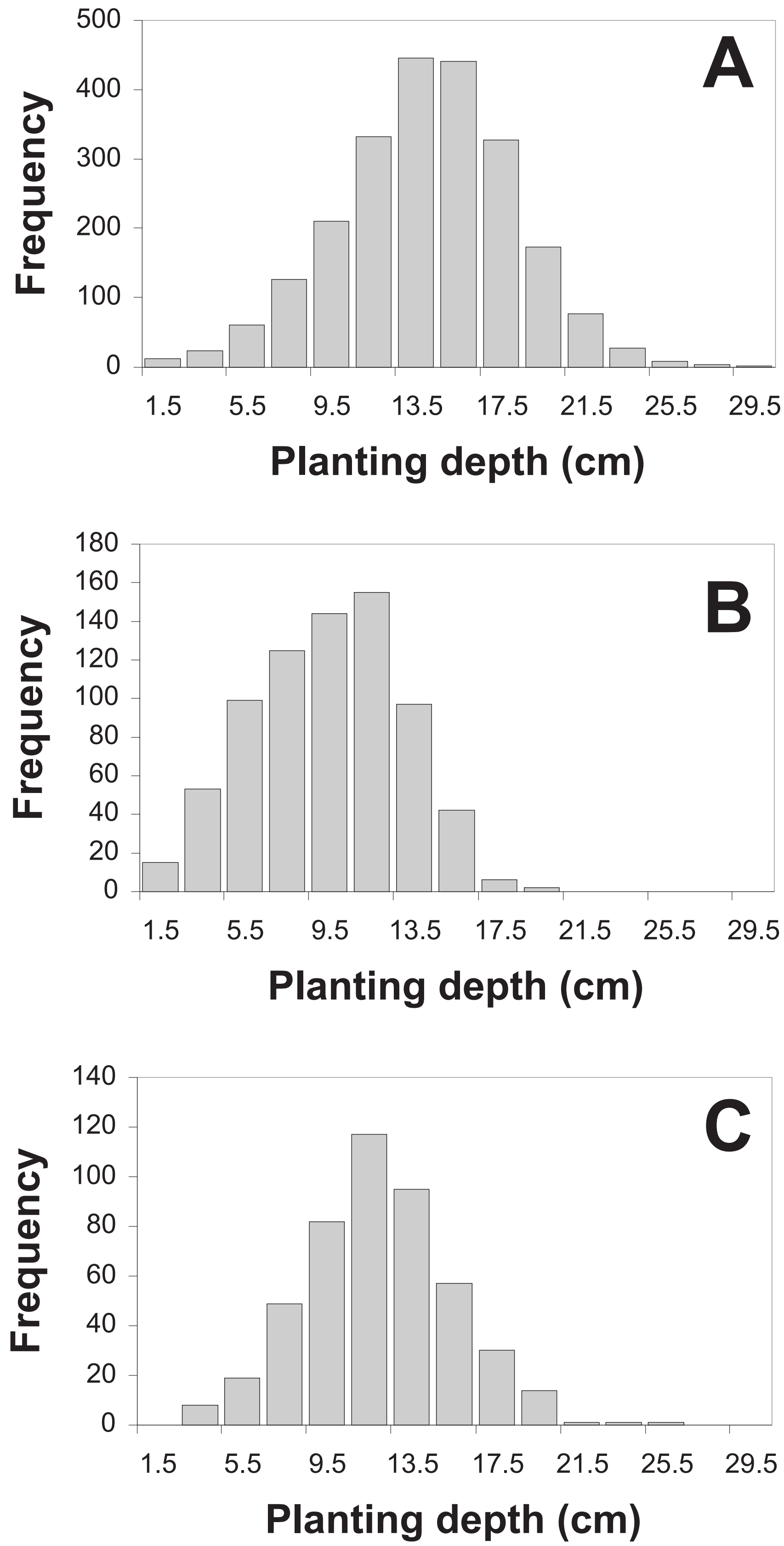

FIGURE 3. Distribution of planting depths by site. Average planting depths were 14,3 cm, 9,2 cm, 11,4 cm, for the Homerville (A), Tattnall (B), and Hampton (C) sites, respectively.

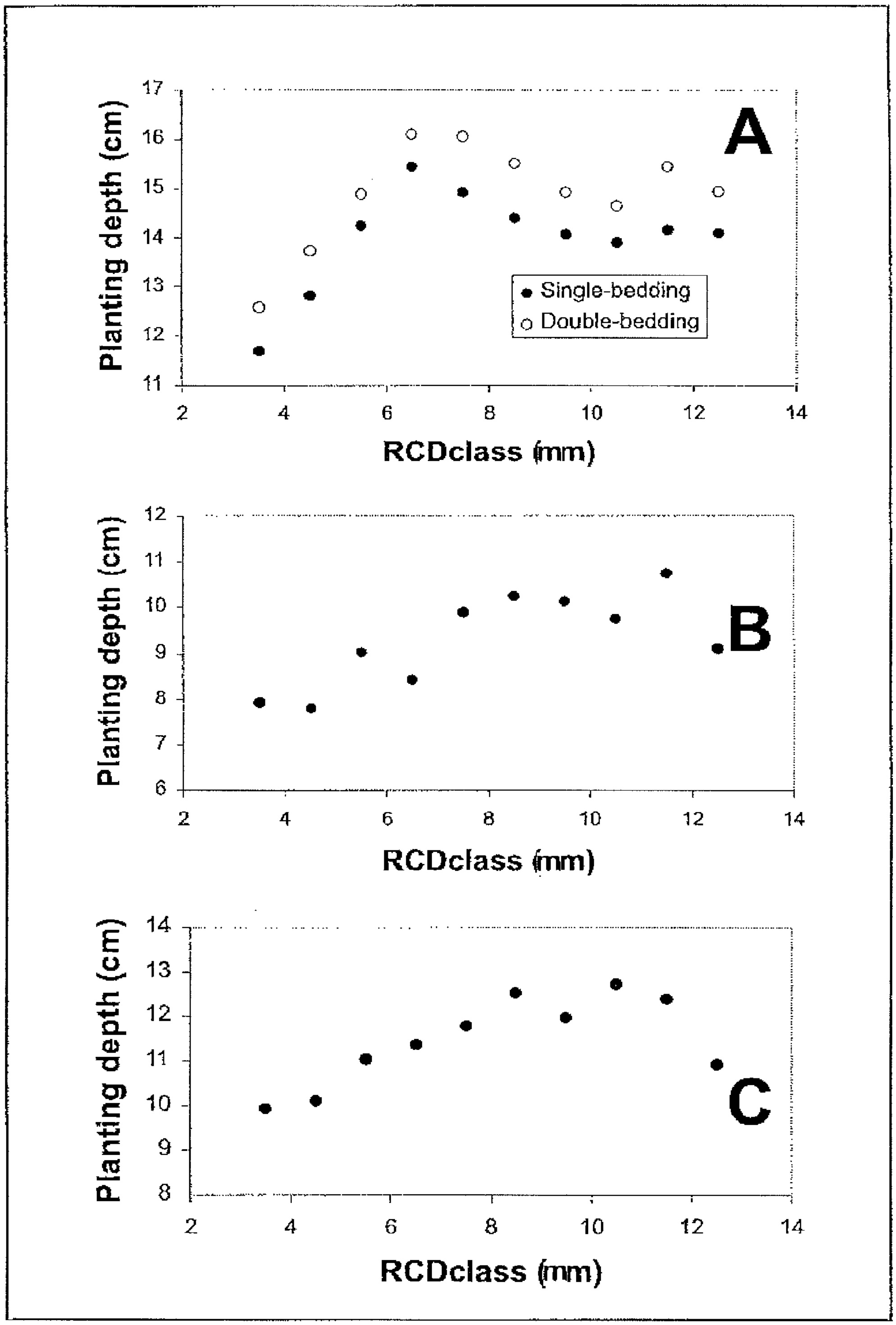

FIGURE 4. Relationship between root-collar-diameter (RCD) class and planting depth. Average planting depths were 13,8 cm, 14,7 cm, 9,2 cm and 11,4 cm for the Homerville single-bed (A – solid point), Homerville double-bed (A – open point), Tattnall (B), and Hampton (C) sites, respectively.

Therefore, to eliminate the potential for confounding, planting depth analyses were conducted separately for the single and double-bedding treatments. The GLM analysis involved a split-plot design with five replications. Herbicide treatment was the main effect and planting-depth category was considered the split-plot. RCD was used as a covariate. Linear, quadratic and cubic contrasts were used to test for relationships between planting depth class and response variables (Mize and Schultz, 1985). Factors were considered significant at the α 0,05 level.

P. taeda

The seedlings at the Hampton and Tattnall sites were hand planted by a company crew on January 28 and February 3, 1993, respectively. RCDs ranged from 3,0 mm to 12,6 mm at the Tattnall site and from 3,1 mm to 12,8 mm at the Hampton site (**Figure 3**). The 4 planting depth categories differed between the Tattnall and Hampton sites. The categories at the Tattnall site were: 1 to 6,74 cm, 6,75 to 9,74 cm, 9,75 cm to 12,24 cm, and 12,25 to 20 cm. At the Hampton site, the categories were: 1 to 9,4 cm, 9,5 to 11,9 cm, 12,0 to 14,4 cm, and 14, 5 to 35,5 cm. Average planting depth (including both small and large-diameter seedlings) was 9,2 and 11,4 cm for the Tattnall and Hampton sites, respectively.

The GLM analysis involved a split-plot design with three replications. Management intensity was the main effect and planting-depth category was considered the split-plot. RCD was used as a covariate. Linear, quadratic and cubic contrasts were used to test for significant relationships.

Regression analyses

Simple regression analyses were used to predict RCD from GLD and planting depth (PD). The model included all planted seedlings and no observations were deleted. One model was developed for *P. elliottii* and one model was developed for *P. taeda*.

RESULTS

The RCD covariate affected tree height of *P. elliottii* on single-beds and affected survival of *P. taeda* at both the Tattnall and Hampton sites (**Table 2**). Planting depth affected survival in three of the studies (**Table 3**). Deeper planting increased survival of *P. elliottii* on single beds by about 7%. At the Hampton site, there was an interaction between the degree of intensive management and planting depth. With the regular level of management, planting depth had no effect on seedling survival. However, under intensive management, survival decreased by 3% when seedlings were planted more than 12 cm deep.

Volume growth was affected by block location in all studies while planting depth had an effect on volume in two studies (**Table 2**). Both DBH and stem volume were smaller when *P. elliottii* were planted more than 15 cm deep on double-beds. In contrast, there was a positive relationship between planting depth and tree volume at the Hampton site. Deep planting had no effect on individual tree volume when *P. elliottii* was planted on single-beds or when *P. taeda* was planted at the Tattnall site.

After removing the small seedlings, the average RCD was 8,5, 7,4 and 7,5 mm for the Homerville, Tattnall and Hampton sites, respectively. The equations created to estimate RCD had adjusted R^2 values greater than 0,75 (**Table 4**). The equations predict that a 5-mm GLD measurement for *P. elliottii* or *P. taeda* planted 15 cm deep would have a 6,5-mm or 8,5-mm RCD, respectively.

DISCUSSION

Seedling survival depends on seedling size, planting method, planting depth and site conditions at time of planting. Although Switzer (1960) recommended planting seedlings at or only slightly below the original ground line on poorly drained old-field sites, we found little adverse effects of planting the root-collar 13 to 20 cm below ground on single-bedded sites that were somewhat poorly-drained (as compared with 1 -12 cm deep). Many poorly-drained sites in the southeastern Coastal Plain are bedded and then operationally planted with the root-collar 10 to 18 cm below the soil surface.

Although depth of planting did not affect DBH at the Tattnall site or on single beds at the Homerville site, there was a negative effect when *P. elliottii* was planted on double-beds. Seedlings planted more than 17,4 cm deep were 5 mm smaller in DBH than seedlings planted less than 12,5 cm deep.

Although many tree planting guides recommend planting *P. taeda* 0 to 7,5 cm deep, the average planting depth used by many company crews is usually greater. For the *P. elliottii* pine site with double beds, 96% of the seedlings were planted deeper than 7,5 cm. For the Hampton and Tattnall sites 85% and 65% of the seedlings, respectively, were planted with the root-collar deeper than 7,5 cm. Senior and Hassan (1983) reported that machine planted seedlings on seven company sites in Georgia and in Alabama averaged about 13 to 18 cm deep. They also report that on two sites, hand planting crews using hoes (i.e. hoedads) planted seedlings that averaged 11,7 and 14,7 cm deep. Apparently, some company reforestation managers are more apt to instruct crews to plant seedlings 9 to 18 cm deep than to follow planting guidelines written before 1980 (Martin *et al*., 1953; Wakeley, 1954; Balmer and Williston, 1974).

Planting seedlings with the root-collar below the soil has minimal affect on tree height when seedlings are less than 6 years old (**Figure 2**). In most cases, the difference in height is less than 5 cm (**Table 1**). Likewise, depth of planting had no effect on heights of *P. elliottii* or *P. taeda* at the Tattnall site. Harms (1969) reported similar results for 10-year-old *P. elliottii*. However, deep planting increased height

TABLE 2. Probability of a greater F-statistic for average diameter at breast height (DBH), height (h), volume per tree and survival of large-diameter (> 5 mm RCD) seedlings planted in the Georgia Coastal Plain.

Species/site/age	df	Source	DBH	Height	Volume	Survival
P. elliottii -	4	Replication	0,080	0,000	0,000	0,002
Homerville	1	Herbicide (H)	0,946	0,469	0,745	0,820
Single-bed	4	Error A				
8 years	1	RCD	0,885	0,044	0,597	0,123
	3	Plant Class (P)	0,718	0,989	0,647	0,052
	(1)	Linear	0,461	0,781	0,270	0,117
	(1)	Quadratic	0,874	0,992	0,899	0,620
	(1)	Lack of fit	0,376	0,850	0,518	0,025
	3	H*P	0,487	0,055	0,369	0,182
	23	Error B				
P. elliottii -	4	Replication	0,000	0,000	0,000	0,998
Homerville	1	Herbicide (H)	0,686	0,812	0,637	0,410
Double-bed	4	Error A				
8 years	1	RCD	0,187	0,702	0,237	0,702
	3	Plant Class (P)	0,012	0,885	0,030	0,985
	(1)	Linear	0,002	0,570	0,007	0,888
	(1)	Quadratic	0,402	0,572	0,193	0,740
	(1)	Lack of fit	0,278	0,830	0,445	0,880
	3	H*P	0,133	0,777	0,080	0,597
	23	Error B				
P. taeda -	2	Replication	0,178	0,066	0,002	0,908
Tattnall	1	Mgt (M)	0,009	0,006	0,008	0,938
7 years	2	Error A				
Single-bed	1	RCD	0,971	0,264	0,897	0,028
	3	Plant class (P)	0,783	0,826	0,483	0,274
	(1)	Linear	0,462	0,656	0,270	0,205
	(1)	Quadratic	0,898	0,402	0,715	0,400
	(1)	Lack of fit	0,441	0,949	0,233	0,124
	3	M*P	0,992	0,990	0,902	0,779
	10	Error B				
P. taeda -	2	Replication	0,023	0,000	0,003	0,001
Hampton	1	Mgt (M)	0,024	0,036	0,006	0,967
7 years	2	Error A				
Single-bed	1	RCD	0,769	0,291	0,543	0,001
	3	Plant class (P)	0,210	0,114	0,173	0,007
	(1)	Linear	0,046	0,023	0,038	0,001
	(1)	Quadratic	0,781	0,911	0,709	0,395
	(1)	Lack of fit	0,925	0,764	0,828	0,704
	3	M*P	0,198	0,290	0,105	0,031
	11	Error B				

growth at the Hampton site (**Table 3**). Seedlings planted deeper than 14,5 cm were about 30 cm taller than seedlings planted less than 9,5 cm deep. Upon occasion, others have also observed a positive correlation between planting depth and seedling height. On one site in Arkansas, Mexal and Burton (1978) reported a positive correlation between planting depth and height of 2-year-old *P. taeda*.

Operational planting by hand or with machines can result in a high percentage of L-rooting or J-rooting (Senior and Hassan, 1983). Some fear J-rooting will kill the seedling (Martin *et al*., 1953) or will be detrimental to growth (Harrington *et al*., 1987; Harrington and Gatch, 1999) or stem straightness (Harrington *et al*., 1999). However, just because a seedling has a bent taproot and compressed lateral roots does not mean its performance will be less than seedlings that originate from direct seeding. In fact, on some sites 32% of the trees originating from seed had bent taproots (Harrington *et al*., 1989). Therefore, bends in the taproot can be "natural" as well as "man-made." In addition, just because a seedling has a straight taproot after planting does not mean the taproot will remain straight. For example, out of 30 seedlings that were carefully planted with straight taproots, 27 had bent taproots 5 years after planting (personal communication; Tim Harrington, 2001).

Several studies have shown that J- and L-rooting are not detrimental to growth (Ursic, 1963; Schultz, 1973; Hay and Woods, 1974; Mexal and Burton, 1978; Hunter and Maki, 1980; Woods, 1980; Seiler *et al.*, 1990; Stroempl, 1990; Harrington and Gatch, 1999). Even so, the concern over planting taproots straight has resulted in two major modifications to tree planting methods: pruning taproots and lateral roots prior to planting (Trewin and Cullen, 1985; Harrington and Howell, 1998), and the "pull-up" method of tree planting (Balmer and Williston, 1974; Trewin and Cullen, 1985; Williston *et al.*, 1992). However, pruning roots in order to avoid J-roots can reduce growth and survival (Mexal and South, 1991; Harrington and Howell, 1998). The "pull-up" method of tree planting involves placing the roots at the bottom of the planting hole and then pulling the seedling up 3 to 10 cm in hopes of straightening the taproot and reducing the number of laterals roots that point upwards. Although the "pull-up" method is taught to students before entering college, it has never been tested to see if this method actually reduces J-roots or improves field performance. In fact, since the "pull-up" method results in roots closer to the soil surface, some believe this practice will increase seedling mortality (Seiler *et al.*, 1990; South, 1999).

GLD is a good predictor of RCD (**Table 4**). Of course, the relationship is dependent on taper and

TABLE 3. Average diameter at breast height (DBH), height (h), volume per tree and survival of large-diameter seedlings planted in the Coastal Plain of Georgia.

Species/Site	Planting class (cm)	Planted trees	DBH (cm)	Height (m)	Volume (m^3)	Survival %
P. elliottii-Homerville-Single-bed	1-12,4	244	9,7	5,5	0,016	68,9b
	12,5-14,9	164	9,8	5,4	0,016	77,9a
	15-17,4	240	9,6	5,5	0,015	71,9ab
	17,5-38	188	9,6	5,5	0,015	78,0a
P. elliottii-Homerville-Double-bed	3-12,4	176	10,5a	6,0	0,020a	80,0
	12,5-14,9	156	10,4ab	5,9	0,019ab	77,3
	15-17,4	251	10,1b	5,9	0,018b	77,8
	17,5-33	227	10,0b	6,0	0,018b	78,5
P. taeda-Tattnall Single-bed	1-6,74	169	12,4	10,5	0,049	99,2
	6,75-9,74	199	12,4	10,5	0,049	98,5
	9,75-12,24	199	12,7	10,5	0,052	99,2
	12,25-20	181	12,3	10,2	0,046	98,4
P. taeda-Hampton Single-bed	1-9,4	183	15,3	10,5	0,072	96,1a
	9,5-11,9	188	15,5	10,6	0,073	95,0ab
	12-14,4	217	15,7	10,7	0,075	95,0ab
	14,5-35,5	169	15,9	10,8	0,078	92,5b

Duncan's Multiple Range Test was conducted when there was a significant F-value for planting depth class. Means with the same letters within the same column and site do not differ significantly (a = 0.05).

TABLE 4. Prediction of root-collar diameter (RCD) in mm using ground-line diameter (GLD) after planting in mm and planting depth (PD) in cm.

Species	**Factor**	**Coefficient**	**Standard error**	**P-value**	**R^2**	**# obs**
P. elliottii	Overall	-	1,1918	-	0,8255	2273
	GLD	1,4027	0,0121	0,0001	-	-
	PD	0,0983	0,0037	0,0001	-	-
P. taeda	Overall	-	0,9652	-	0,7729	1912
	GLD	1,1579	0,0100	0,0001	-	-
	PD	0,0454	0,0051	0,0001	-	-

planting depth. Apparently, *P. elliottii* had more taper than *P. taeda*. It is assumed this difference is related to top-pruning the *P. elliottii*. Prior to planting, the *P. elliottii* and *P. taeda* seedlings had average heights of 29 and 46 cm, respectively.

Although planting depth can affect seedling survival (**Figure 1**), most researchers in the southern United States do not report planting depth for silvicultural treatments such as ripping, bedding, or machine planting. Therefore, one might ask if the increase in survival observed from these treatments are simply due to deeper planting, or to some other soil-related factor. In cases where survival is increased by 14% following bedding (McKee and Wilhite, 1986), is this increase due to planting seedlings deeper than on non-bedded areas? Likewise, when machine planting increases seedling survival by 10 to 23% (Barber, 1995; Wheeler *et al*., 2002), is this simply due to planting seedlings deeper? Perhaps in the future researchers in the United States will document planting depth in order to ascertain why certain treatments affect survival. Although some have speculated about this effect in the past, our data are the first in the United States to show that a site preparation method can affect planting depth.

CONCLUSIONS AND RECOMMENDATIONS

Deep planting of open-rooted pine seedlings on well-drained sites will sometimes increase stand volume by improving survival without decreasing individual tree growth. Even so, some tree planting guides place more emphasis on keeping the tap-root straight than on planting the seedling 15 cm deep (a depth common for machine planted seedlings). Planting guidelines in the southern United States should be rewritten to: (1) emphasize the "proper" depth of planting (to increase seedling survival), (2) explain the species/site/planting depth interaction for survival, (3) de-emphasize intuitive beliefs that roots should look "normal" after planting, (4) eliminate unnecessary refinements in planting technique, (5) explain some of the advantages of machine planting, (6) discourage pruning roots by tree planters, and (7) cite references to support the tree planting recommendations. Researchers who wish to explore why site preparation treatments affect survival are encouraged to document the effects of treatments on planting depth.

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Editor's Comment:

The authors stated "In this paper we report planting depth in cm. We believe this superior to qualitative categories like 'shallow', 'normal' and 'deep'. We believe these recommendations would improve planting of open-rooted seedlings in the United States"

While the authors noted that "container-grown seedlings" are the norm in South Africa, the main referee states "bare-root seedlings are not commonly planted in South Africa and we don't generally have waterlogged sites, but the issue of planting depth is an interesting one and worth bringing to the notice of the South African forestry research community"

The above statements are most valid but I believe that this paper should generate "Comment to Editor" debate response from Southern African forestry practitioners on planting depth and open-rooted planting and a possible 'rethink'!

NOTE: An earlier draft of this paper was rejected by editors of the Southern Journal of Applied Forestry. Two reviewers said to accept the paper and one said it should be rejected.

The editor said: "Enclosed are the comments of three reviewers and an associate editor for your manuscript entitled "Effect of planting depth on growth of large-diameter slash pine and loblolly pine seedlings" (SJAF 3089). In the opinion of the associate editor and one reviewer, the manuscript suffers from two major shortcomings. First, the effect of planting depth on growth is already well documented in the literature - as illustrated by your own literature review. Second, the relationship between RCD and GLD in light of planting depth has little practical importance. In light of these shortcomings, I regretfully return your manuscript as unsuitable for publication in the Southern Journal. "