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Date of sowing and emergence timing affect growth and development of loblolly pine seedlings

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Application. Nursery managers can manipulate seedling morphology by varying sowing date as well as seedbed density. Sowing earlier can increase seedling caliper and biomass. However, when sowing early in a bareroot nursery, undercutting may need to be employed to limit height growth. Delaying sowing will delay the formation of the initial bud. Sowing in May or June will likely decrease seed efficiency.

Abstract. Loblolly pine (*Pinus taeda* L.) seeds were sown from February to June in Alabama, U.S.A. If sowing was conducted in May or June, seedling emergence was reduced and seedling mortality increased. Seedlings from earlier sowings grew to greater sizes, but seedlings from later sowings grew later into the fall. Within any given sowing date, the earliest seedlings to emerge grew largest. Seedlings from the February sowing formed buds in mid-summer, flushed, and in some instances flushed yet again. However, by early October, not all seedlings from May and June sowings had formed an initial bud.

Introduction

Forest nurseries in the southern United States produce more than one billion loblolly pine (*Pinus taeda* L.) seedlings annually (McDonald and Krugman 1986). Nearly all of these seedlings are grown in bareroot nurseries from seeds sown throughout the spring. Most sowing is done during the month of April, but occasionally it is begun as early as March. More often, it is delayed until May (Boyer and South 1988).

Sowing too early may cause slow emergence while sowing too late may result in variable emergence or early mortality due to heat (May 1985). Moreover, since time of sowing can affect seedling size, the sowing date will affect the production of high quality loblolly pine seedlings.

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The effect of emergence timing in loblolly pine seedbeds has already been demonstrated for seeds sown at the same time. Treatments which hasten emergence generally increase root-collar diameter at the end of the season (Boyer et al. 1985). Furthermore, the first seedlings to emerge in a stand tend to become the largest (Mexal and Fisher 1987). In addition, when half-sib families of loblolly pine are sown separately, the families which germinate first attain the greatest average diameters (Boyer et al. 1987). It is not known if the effects of emergence timing vary when seeds are sown at different times of the year. The objectives of this experiment were to compare the growth and development of loblolly pine seedlings from seeds sown at different times and to determine if emergence timing effects may be influenced by the date of sowing.

Materials and methods

Seedling culture

The experiment took place at Auburn, Alabama, U.S.A., which is situated at approximately 32° 30′ N latitude, 85° 30′ W longitude, and 200 meters elevation. Seeds from a single half-sib family of loblolly pine were sown on six dates in 1985: 20 February, 13 March, 3 April, 24 April, 15 May, and 5 June. The female parent was from northeastern North Carolina. U.S.A. (approximately 35° 30′ N latitude, 76° 30′ W longitude, and elevation near sea level), and was open-pollinated in a seed orchard. The seeds were stratified at 2—4 °C for six weeks prior to each sowing and treated with triadimefon (Bayleton® 50 WP, 0.25 g 100 g^{-1} seed) to protect against fusiform rust, and thiram (Arasan® 42 S, 8.3 ml 100 g^{-1} seed), as a bird repellent. Seeds were sown in rows 15 cm apart at two different spacings between seeds in a row (2 and 3 cm). This resulted in sowing densities of 333 and 222 seeds per square meter. Seeds were sown in 1.2 × 1.2 m wood frames filled with coarse sand. The frames extended approximately 15 cm above pits filled with coarse sand 1 m deep, so there were no restrictions to root growth. Seeds were pressed slightly into the sand, and covered with approximately 1 cm of pine bark as a mulch. Each sowing date-density combination occupied one frame. Four replications were arranged in a randomized complete block design (there was a total of forty-eight plots).

Plots were watered daily throughout the germination period and early seedling growth phase. As roots grew deeper into the sand, waterings were less frequent. Plots were sprayed with captan (Captan® 50 WP, 11.2 kg ha^{-1}) after sowing to control damping off. During the fusiform rust spore flight (mid-April through early June), triadimefon (Bayleton® 50 WP, 0.56 kg ha^{-1}) was sprayed approximately once every three weeks. The seedlings were fertilized weekly with 20-20-20 (N:P_2O_5:K_2O) at approximately 130 kg per ha per application, beginning after emergence. The first three sowings received 17 applications (ending 31 July, 14 August, and 4 September). Fertilization of the later sowings was ended in early September which resulted in 15, 13, and 10 applications.

Seedling measurements

Ten seedlings were selected at random (from the same two rows of each plot), marked and measured in place for height and root-collar diameter every four weeks from 18 June until 5 November, 1985, and again on 20 January, 1986. In order to determine if there were differences in early growth among sowing dates, comparisons were made using estimates of heights and diameters (from interpolation) at 100 and 125 days following emergence. Late-season growth and growth cessation were also compared by computing growth after 13 August and estimating the date (from interpolation) when height reached within 1 cm and diameter reached within 0.5 mm of the final value. Each time the selected seedlings were measured for height and diameter, all the trees in those two rows of the plot were checked for bud formation. Seedlings were classed as having set a bud even if it had flushed again. All the seedlings in these same two rows were tagged with their emergence date and lifted in February for measurements of height, diameter, and over-dry weights of shoots and roots.

Data analysis

Three types of analyses were performed to establish and understand the relationships within the data set. The analyses included:

- analysis of variance to assess the effects of sowing date and density on seedling characteristics,
- regression analysis to model the response of seedling characteristics to: sowing date and time of seedling emergence within a sowing date, and
- graphical analyses to illustrate the change in growth rate over time.

Each of these procedures is described below.

Analyses of variance were conducted to test sowing date and sowing density effects. Unadjusted plot means were tested using the model: y = sowing date, sowing density, the interaction between sowing date and density, and block (Table 1).

Emergence percent and subsequent mortality varied within and among sowing dates. Damping-off was especially severe for the 3 April sowing. This variation, together with the two sowing densities, resulted in a wide range of densities. Year-end densities ranged from 88-210 per m^2 for the low sowing density (222 per m^2) and 76—313 per m^2 for the high sowing density (333 per m^2). For this reason, when using regression techniques to fit a response model, the six sowing date means were adjusted for density (for Figures 1—6).

Second- and third-order polynomial functions were used to examine the effect of sowing date on morphology (Mize and Schultz 1985). Means (adjusted for density) for early height, late height, final height, final diameter, and final seedling weight were regressed over sowing date. Models were also computed to examine when seedling growth reached within 1 cm and 0.5 mm of final height and diameter, respectively. It is not intended that these models be used as predictive models.

Linear regressions of unadjusted means for height, diameter, shoot weight and root weight on emergence date were computed separately for each sowing date. These regressions were weighted by the number of seedlings which emerged on a particulatr date.

To illustrate patterns of growth increment, curves were drawn which approximated the changes in height and diameter growth rates during the growing season. This was done using data collected from monthly measurements. To keep the figure relatively simple, only three of the sowing dates were included.

Results

Seedling emergence

Seedling emergence varied by sowing date (Table 1). Although seedling emergence was delayed for the February and March sowings, the percent emergence was greater than for the May or June sowings (Table 2). Seedling mortality (seedlings that emerged and then died) was also affected by sowing date. Seedlings from the first two sowings exhibited the lowest mortality. Due to exessive damping-off, the 3 April sowing had both reduced emergence and the greatest seedling mortality.

Seedling growth

Sowing density greatly affected diameter growth (Table 1). After just 100 days, seedlings sown at the lower density were already larger in diameter than seedlings sown at the higher density. Due to excessive damping-off,

Table 1. Calculated F-values from analyses of variance for emergence, mortality, early growth, late growth, timing of growth cessation, morphology of seedlings lifted at the end of the season, and percent bud-set on 10 September.

Factor	df	Seedling emergence	Seedling mortality	Growth 100 days after emergence		Growth 125 days after emergence		Growth after 13 August		Growth cessation		End of growing season				Bud-set
				Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter	Shoot weight	Root weight	
Sow date (S)	5	10.9***[1]	4.2**	44.7***	10.2***	52.5***	3.9**	161.7***	25.5***	23.8***	8.0***	278.1***	18.8***	26.0***	11.9***	1006.5***
Density (D)	1	0.2	0.0	2.9	30.9***	2.3	66.2***	11.0**	33.7***	5.0*	12.0**	25.4***	51.7***	42.0***	41.3***	2.1
S * D	5	0.7	0.2	1.4	1.4	2.0	1.7	3.7**	2.2	0.7	0.9	5.0**	0.9	1.5	1.6	2.2
Block	3	3.1*	1.6	0.4	0.6	0.8	0.2	2.9	0.5	1.5	3.8*	0.3	1.9	0.8	0.3	1.5

[1] Asterisks refer to significance level for factor.
*** for probability less than 0.001
** for probability less than 0.01 but greater than 0.001
* for probability less than 0.05 but greater than 0.01 (error degrees of freedom = 33)

the 3 April sowing ended up with the lowest seedbed density and therefore produced the heaviest and largest diameter seedlings (Table 2). However, after adjusting for differences in final seedbed density, the growth curves indicate that sowing in February would have produced seedlings with larger diameters (Fig. 1).

Although the adjusted growth curves presented in Fig. 1 show the effect of sowing date on height and diameter, they do not clearly demonstrate the initial growth differences which occur after emergence. Differences illustrated in Fig. 2 indicate the earliest and latest sowing dates exhibited less height and diameter growth over the first 100 days following emergence than the middle sowing dates. Over the next twenty-five days, height growth for the later sowing dates decreased sharply compared with

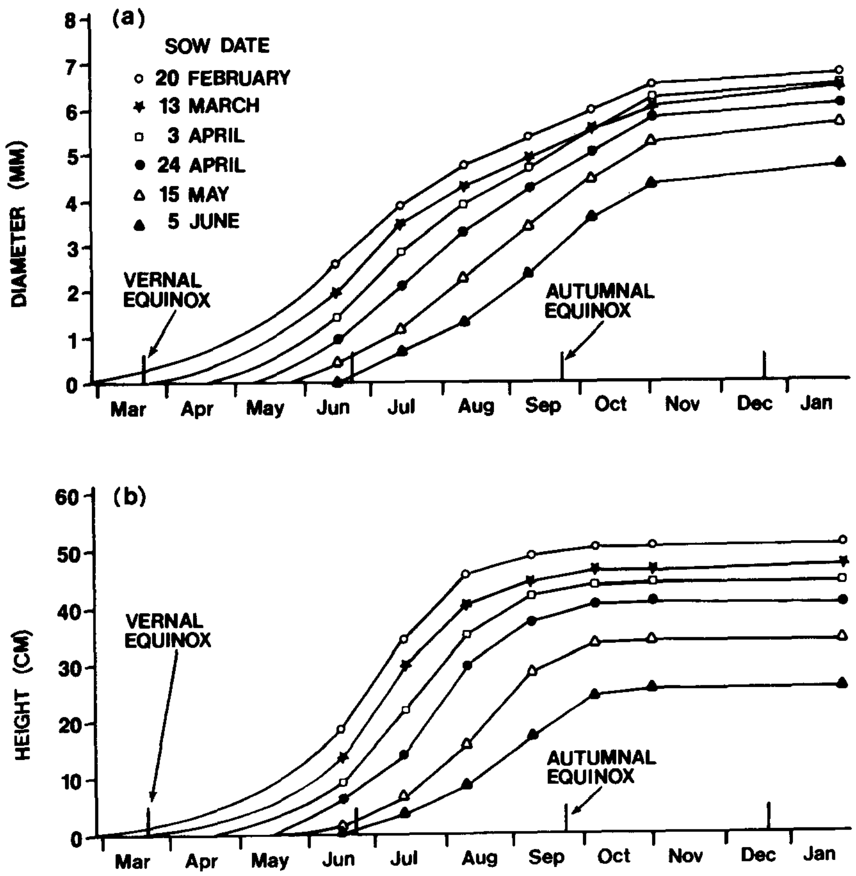

Fig. 1. Effect of sowing date on diameter and height growth of loblolly pine seedlings (after adjustment for differences in seedbeed density).

Table 2. Seedling emergence, mortality, final density, and morphology for each sowing date.

Sowing date	Emergence begins	50 % emergence	Emergence ends	Seedling emergence	Seedling mortality	Sowing density	Final density	Final height	Final diameter	Shoot weight	Root weight	Total weight
	(Days after sowing)			(%)	(%)	(#/m^2)	(#/m^2)	(cm)	(mm)	(g)	(g)	(g)
20 Feb.	14	21	35	97	19	222	180	51.6	7.55	10.86	2.87	13.74
						333	250	47.6	6.38	7.20	1.94	9.14
13 March	13	18	25	97	16	222	189	48.0	7.52	9.95	3.07	13.02
						333	254	44.8	6.35	6.81	1.93	8.70
3 April	11	13	17	92	42	222	124	46.4	8.35	12.68	4.73	17.40
						333	172	43.0	7.01	8.52	2.73	11.25
24 April	5	8	13	98	27	222	154	42.2	7.41	8.65	3.03	11.68
						333	242	38.1	5.98	5.65	1.88	7.53
15 May	6	9	16	93	36	222	134	32.9	6.90	6.84	3.11	9.95
						333	217	33.7	5.85	4.87	1.81	6.68
5 June	5	8	15	88	27	222	150	25.7	5.48	3.34	1.53	4.87
						333	217	26.6	4.99	2.77	1.22	3.98
Average						222	155	41.1	7.23	8.72	3.06	11.78
						333	225	39.0	6.09	5.97	1.92	7.88

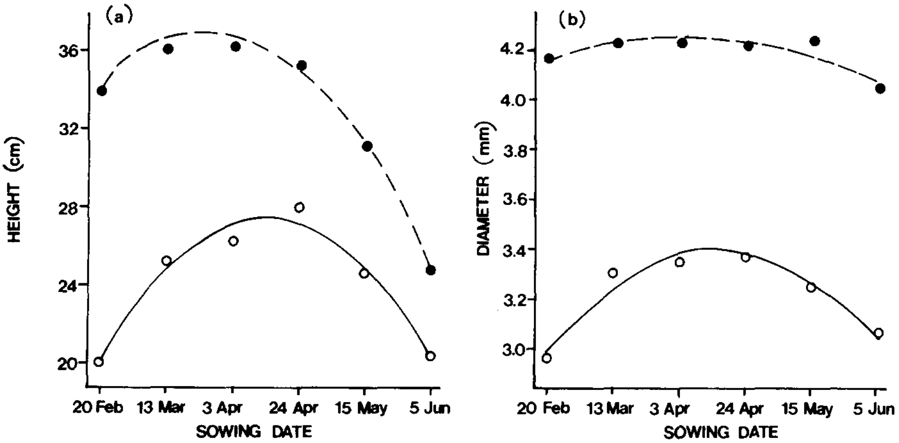

Fig. 2. Effect of sowing date on height (a) and diameter (b) of loblolly pine seedings 100 days (○——○) and 125 days (● — — ●) after emergence. F values for the overall models are significant at $P < 0.01$, except for diameter at 125 days ($P = 0.09$).

the early sowings, while diameter growth for the earliest and latest sowings was greater than for the middle sowing dates during the 25 day interval. Even though growth was initially slower, seedlings from the February and March sowing ended up being taller and larger in diameter than seedlings from the 24 April sowing (Fig. 1). This was due to the longer growing season for the early sowings.

Even though seedlings from earlier sown seeds grew taller, they completed their growth earlier in the season. Seedlings from seeds sown in May or later exhibited more than 50% of their growth after mid-August (Fig. 3). Seedling diameter growth continued later than height growth. While height growth was 97—98% complete by late September-early October, diameter growth was 91—93% complete in late October (Fig. 4).

As a result of decreased shoot growth in the fall, seedling biomass production was sharply reduced for the later sowings. However, due to continued root growth in the fall, root weights did not vary nearly as much with sowing date (Fig. 5). Therefore, seedlings from late sowings had a greater proportion of their biomass in roots. The rate of seedling biomass loss due to delayed sowing in late spring was very great. Total seedling dry weight was reduced by about 0.7 g per week from April to May, and 1.2 g per week from May to June.

For five of the sowing dates, time of emergence within a sowing date had roughly the same effect on morphology for each sowing. The third sowing, which suffered high mortality (due to damping-off), was the

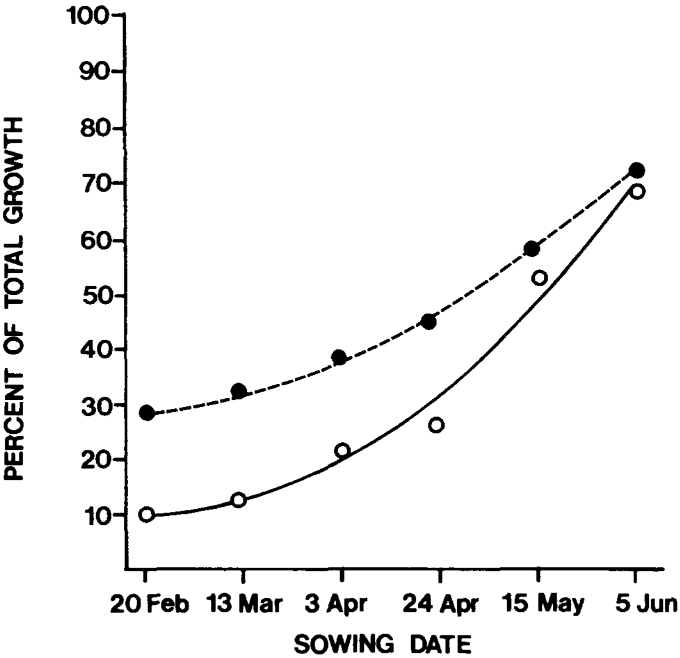

Fig. 3. Percentage of height (o——o) and diameter (• — — •) growth that occurred after 13 August as affected by time of sowing. F values for the overall models are significant at $P < 0.01$.

exception. For an unknown reason, the slope for the effect of emergence date on morphology was much steeper for this sowing. Aside from this sowing, a one-day delay in emergence resulted in a decrease of 0.5—0.8 cm in height, 0.12—0.16 mm in diameter, 0.22—0.47 g in shoot dry weight, 0.06—0.17 g in root weight, and 0.3—0.6 g in total weight for the five remaining sowings (Table 3).

There was a significant interaction between sowing date and sowing density for height growth after 13 August (Table 1). Sowing at the higher density reduced height growth only for the first four sowings. There were no other interactions between sowing date and sowing density.

From the monthly measurements of height and diameter, curves were drawn which approximated the changes in daily growth increment for three of the sowings (Fig. 6). The general shapes of the height growth curves were similar, although the last sowing never reached the high rate of height growth experienced by seedlings from earlier sowings. Diameter growth curves had different shapes. For early sowings, growth rate reached a peak, decreased, leveled off at a moderate rate for up to two

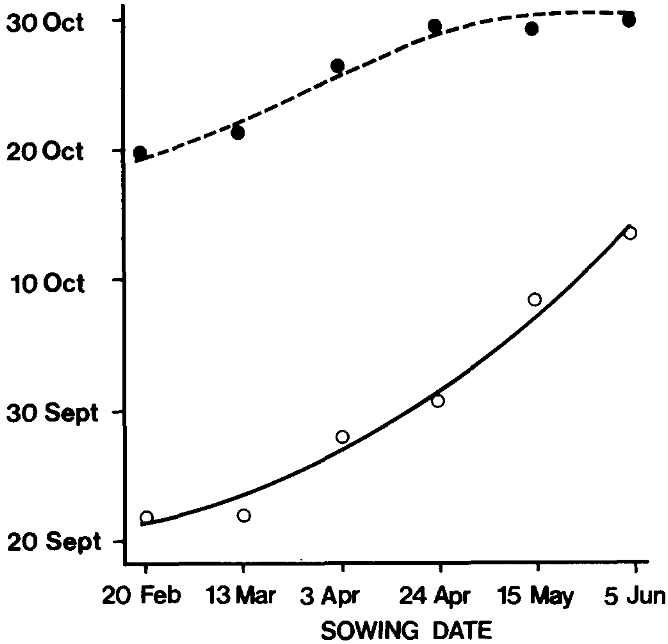

Fig. 4. Effect of sowing date on date to reach within 1 cm of final height (o——o) and date to reach within 0.5 mm of final diameter (• — — •). The F value for the overall model for height growth cessation is significant at $P < 0.01$. The F value for the overall model for diameter growth cessation is significant at $P < 0.05$.

months, then decreased sharply. For the latest sowing date, however, a leveling off did not occur, as the peak in diameter growth rate did not occur until early fall.

Initial bud formation

Timing of initial bud formation was strongly influenced by sowing date. The earlier the date of sowing, the earlier the first bud was formed. Ninety-five percent of the seedlings from the February sowing formed their first bud by late July (Table 4). Seedlings from April-sown seeds reached this stage of development by mid-August or early September. Seedlings from seeds sown in May or June did not reach 95% budset in their first season. On 8 October, 86% of the seedlings from the May sowing had formed a bud while only 29% of the seedlings from the June sowing had a bud. Seedlings were approximately the same size when the first bud was formed (Table 4). For the February, March and late April sowings, initial bud formation was complete at approximately the same age after emergence.

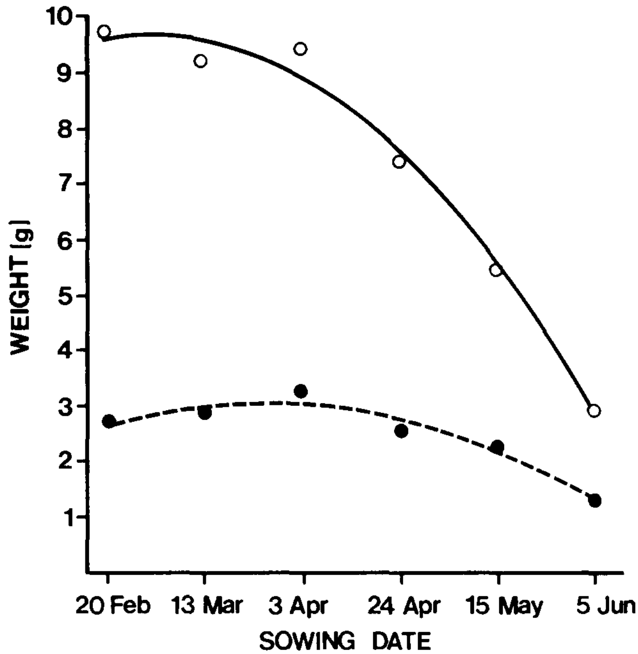

Fig. 5. Effect of sowing date on shoot weight (o——o) and root weight (• — — •) at end of season. F values for overall models are significant at $P < 0.05$.

Table 3. Slope coefficients, by sowing date, for simple linear regressions of morphological measurements as a function of emergence day.

Sowing date:	20 Feb	13 March	3 April	24 April	15 May	5 June
			Slope coefficients			
Height (cm)	−0.67 ** [1]	−0.51 *	−1.68 **	−0.78 *	−0.84 **	−0.56 **
Diameter (mm)	−0.16 **	−0.13 NS	−0.57 **	−0.13 NS	−0.16 **	−0.16 **
Shoot weight (g)	−0.47 **	−0.27 *	−1.60 **	−0.23 NS	−0.41 **	−0.22 **
Root weight (g)	−0.13 **	−0.08 NS	−0.67 **	−0.06 NS	−0.17 **	−0.09 **
Total weight (g)	−0.61 **	−0.35 *	−2.27 **	−0.29 NS	−0.58 **	−0.31 **

[1] Asterisks refer to probability of a greater t-value for H_0: slope = 0:
** = $P < 0.01$
* = $P < 0.05$
NS = $P < 0.05$

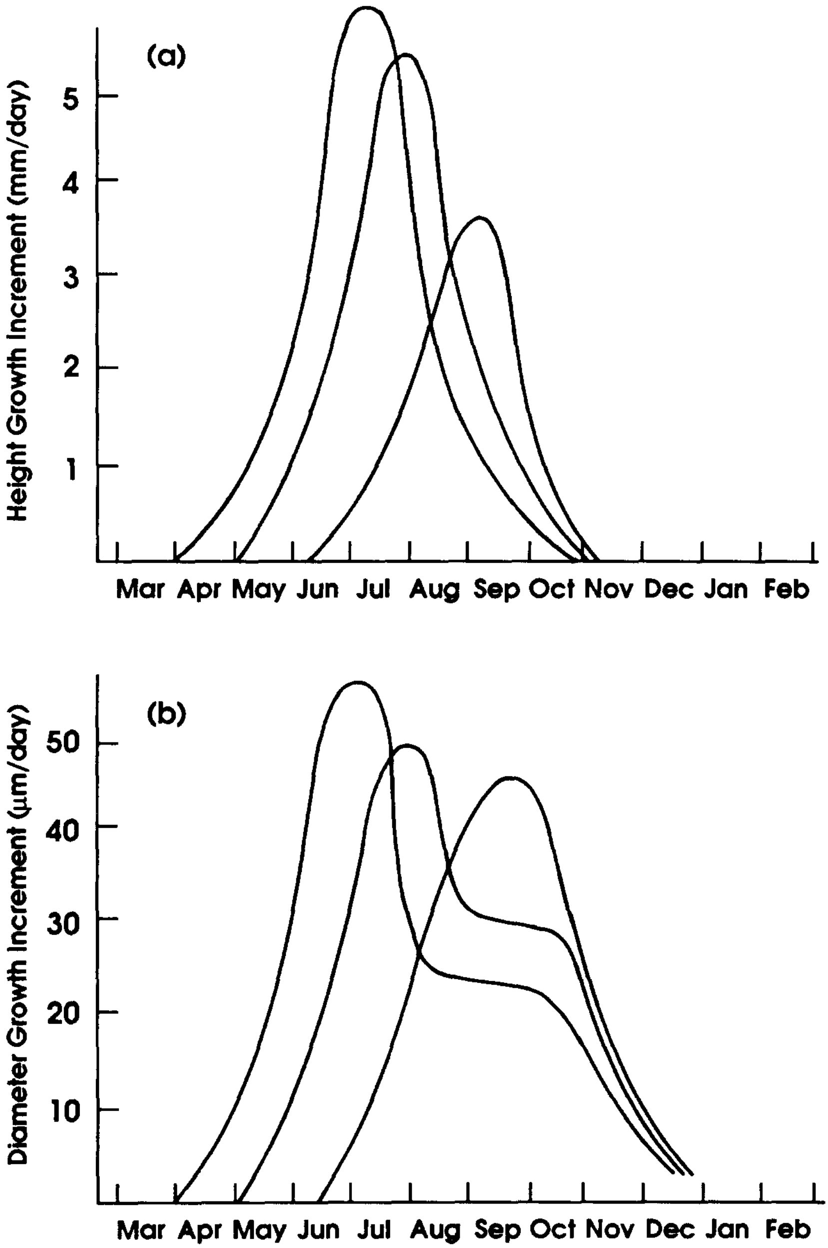

Fig. 6. Height (*a*) and diameter (*b*) growth rate curves for three different sowing dates: 13 March, 24 April, and 5 June (left to right).

Table 4. Date of 95% initial bud-set and mean seedling height and diameter on this date.[1]

Sowing date:	20 February	13 March	3 April	24 April
95% initial bud-set	26 July	9 August	16 August	10 September
Days after emergence	135	131	122	131
Height (cm)	38	38	36	37
Diameter (mm)	4.4	4.2	4.3	4.4

[1] Dates of bud-set and height and diameter means from interpolation between measurements.

Discussion

Mexal (1982; 1984) demonstrated that delaying sowing one week (after 15 April) could reduce biomass production in loblolly pine seedbeds by 7%. Our data support these findings. There was aproximately a 5% reduction in seedling dry weight with a one week delay after 24 April and a 14% reduction per week after 15 May. However, in our study, this relationship does not appear to be linear. Delaying sowing after 3 April affected growth more than delaying sowing between 20 February and 3 April (Fig. 5). This is in agreement with van den Driessche (1969) who found that with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings a much greater reduction in height and dry weight occurred when delaying sowing from May to June than from April to May or March to April. In contrast to these findings, Sorensen (1978) found that delaying sowing of Douglas-fir from April to May reduced height growth more than delaying from May to June.

Within each sowing (Table 3), time of emergence had a strong effect on seedling morphology. Later emerging seedlings tended to have smaller heights, diameters, and dry weights. This phenomenon has been demonstrated for loblolly pine in the past (Boyer et al. 1985; Boyer et al. 1987; Mexal and Fisher 1987). With the exception of the third sowing which suffered such high mortality, the effect of emergence timing on diameter did not differ greatly by sowing date (even though germination characteristics varied with sowing date).

The differences in emergence timing between seedlings, within a given sowing date, resulted in a much greater effect on seedling morphology than delaying sowing by the same amount of time. A one week difference in emergence timing within a sowing reduced seedling weight by 2 to 5 times more than a one week delay in sowing. Morphological differences resulting from sowing date are due to variation in growing time and environmental conditions. However, within a sowing, the greater differences due to time of emergence are due to the competition which occurs between seedlings within a stand.

As expected, sowing density had a strong effect on seedling morphology. Seedlings sown in May at 222 seed/m^2 were heavier and had larger diameters than seedlings sown in February at 333 seed/m^2. This indicates that when nursery managers are forced to sow some seed lots late (to correct for unexpected losses during germination), they should consider sowing at low densities to take advantage of the increase in diameter and root growth. Regardless of sowing date, the lower seedbed density increased root weight proportionately more than shoot weight. On average, root weight was increased by 59% by sowing at the lower density while shoot weight increased by only 46%.

Biomass partitioning was also affected by time of sowing. Seedlings from the early sowings had a greater amount of biomass allocated to the shoots than seedlings from late sowings (Fig. 5). Therefore, to keep seedlings from early sowings from becoming out of balance, nursery managers may need to reduce shoot growth by scheduling undercutting sooner.

Rowan and Marx (1976) reported that delaying sowing after 29 April could reduce loblolly pine seedling emergence by about 0.6 percent per day. Mexal (1982) also found that delaying sowing in April and May could reduce loblolly pine seedling emergence by about 0.5% per day. In our study, emergence was reduced by about 0.24% for each day after 24 April. In addition to a decrease in seedling emergence, our data indicate that seedling mortality can increase when sowing is delayed. Therefore, seed efficiency will be reduced when delaying sowing reduces emergence and increases seedling mortality.

Sorensen (1978) reported that delaying sowing delayed budset. This was certainly true for our study. For 1—0 loblolly pine seedlings, the timing of initial bud formation appears to be related to seedling size or plastochron age rather than photoperiod or temperature (Cannell 1986). Since seedlings from the early sowings formed the initial bud in mid-summer, and the date (when 95% of the seedlings had formed a bud) varied considerably among sowing dates, it is unlikely that photoperiod played a significant role in this developmental process.

Initial bud formation occurred aproximately 131—135 days after emergence (except for the third sowing which completed budset about 10 days earlier). Huberman (1940) and Williams (1987) sowed loblolly seed in March and also found the seedlings formed their first bud about 140 days after emergence.

Huberman's seedlings weighed only about 0.9 g and were only 10 cm tall when they first formed a bud. Due to greater fertilization and irrigation, our seedlings averaged 36—38 cm in height and 4.2—4.4 mm in diameter at time of initial bud formation. The dissimilarity in size of seedlings for the two studies but the similarity in time to bud formation suggests that the plastochron age may be more important for bud formation than seedling size *per se*. This would seem to be a suitable area for future research.

Many seedlings from the earlier sowing dates flushed again after setting a bud. Several seedlings had three flushes. Each consecutive flush tended to be shorter than the previous flush. This, in addition to the delay between flushes, explains in part the reduced late-season growth for early sowing dates. Seedlings from later sowings, still in their first flush, were in a more rapid growth state during late summer (Fig. 6).

A comparison of the incremental growth curves (Fig. 6) reveals that the pattern of growth is different for height and diameter. Until about midsummer, the patterns of growth are similar. However, in the fall, height growth is restricted by photoperiod while diameter growth continues. Diameter growth decreases in November and December as a result of reduced fertilization and low temperature.

Conclusions

Even though sowing in February or March can cause loblolly pine seedlings to emerge at a slower rate, seedling mortality will likely be lower than for sowings conducted in May or June. However, when sowing prior to April, nursery managers will need to initiate height control measures sooner to avoid producing unbalanced seedlings. Sowing after April may result in some seedlings not setting an initial bud in the nursery. When forced to sow in May, nursery managers should considerer sowing at lower seedbed densities to offset the reduction in seedling size. Regardless of time of sowing, the size hierarchy within a seedbed will still be related to time of emergence. However, due to competition effects, the effect of emergence timing on seedling morphology appears to be of greater importance within a seedbed than among seed lots sown on different dates.

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