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Size hierarchy in conifer seedbeds. I. Time of emergence[1]

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Application. Delayed time of emergence decreases nursery seedling size and increases percentage culls. Seed treatment to speed emergence will increase seedling size and may improve crop uniformity.

Abstract. Studies conducted at two pine nurseries in the South and one in the West empirically related the genesis of seedling size hierarchies to time of emergence (TOE). *Pinus taeda* seeds were operationally sown at the southern nurseries in late April and *P. ponderosa* in late July at the western nursery. Germinated seedlings were tagged with color-coded plastic rings (20 mm dia.) every other day until germination was complete. Emergence was complete in 16-20 days. Growth response to TOE effects was determined 8 and 15 months, respectively, after sowing.

Results were strikingly similar across nurseries; TOE strongly influenced germinant mortality and shoot biomass decreased 3.5% per day elapsed from initial emergence. That is, seedlings emerging 10 days after emergence began were 35% smaller at harvest than those emerging first. Late germinants accounted for significantly more culls among harvested seedlings than early germinants. Also, TOE accountend for more than 80% of variation in harvest biomass. Findings suggest that the germination period should not exceed 5 days. Response models are proposed to elucidate TOE effects in nursery operations.

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Introduction

Seedlings in a nursery seedbed routinely vary greatly in size resulting in distinct size hierarchies at harvest. Size variation among seedlings has been attributed to many factors, including: genetic variability, incomplete stratification, growing density, and variability in such cultural practices as fertilization and irrigation. Crop yield and subsequent value are determined largely by the size and uniformity of lifted seedlings. To improve uniformity and field transplant performance, factors causing size variation within seedbeds must be identified and controlled.

Rapid, complete emergence generally is perceived as important (Dunlap &

Barnett 1984) and stratification requirements to speed germination have been determined for many coniferous species (McLemore 1969; Schopmeyer 1974). Boyer and others (1985) found that increasing the length of stratification could increase nursery seedling caliper. However, prolonged stratification appeared to be detrimental in one test. Stratification effects on crop uniformity are undetermined.

The extent to which size hierarchies express differences in seedling emergence rates within coniferous seedbeds has received minor attention. Logan and Pollard (1979) reported early emerging seedlings of Japanese larch were larger than those emerging later. Venator (1973) reported rapid emergence improved the height at 150 days of containerized *Pinus caribaea* seedlings. However, Griffin (1975) found rate of emergence had little effect on the final biomass of *P. radiata* seedlings.

The objective of this study was to determine the effect of time of emergence on seedling morphology and mortality in a nursery seedbed.

Materials and methods

Pinus taeda L.

Loblolly pine seeds collected from native stands in Texas and Oklahoma were sized and stratified before sowing (Table 1). Two seedlots were stratified 17 d and sown in early May 1977 at a bareroot nursery near Ft. Towson, OK. Two additional seedlots were stratified 45 d and sown in late April 1977 at a nursery near Magnolia, AR. Seeds were sown with the StanHay Precision seeder at a target population density of $300/m^2$. Twelve $0.36\ m^2$ (0.3×1.2 m) plots were arranged at random throughout the operational sowing. A 20 mm color-coded plastic ring was placed over each emerged seedling when the hypocotyl was in the crook stage. Seedlings were tagged on alternate days

Table 1. Sequencing of seed treatment and emergence of loblolly pine at Oklahoma and Arkansas nurseries, and ponderosa pine at the Albuquerque nursery. Pretreatment refers to stratification for loblolly pine and a 24 h water soak for ponderosa pine.

	Oklahoma		Arkansas		Albuq.
	Lot 1	Lot 2	Lot 1	Lot 2	
Pretreatment	17 d	17d	45 d	45 d	1 d
Sow date	5/4/77	5/4/77	4/25/77	4/28/77	7/30/84
Emergence (begin)	5/11/77	5/11/77	5/5/77	5/7/77	8/9/84
Emergence (end)	5/20/77	5/20/77	5/15/77	5/15/77	8/19/84
Harvest	12/77	12/77	12/77	12/77	11/85

beginning at about 10% emergence. The emergence period spanned 9-11 days.

Seedlings were irrigated and fertilized according to conventional practices for each nursery. In December 1977, all seedlings were hand lifted and sorted by emergence day. Survival, height, caliper and shoot fresh weight were recorded by emergence day. The proportion of plantable seedlings (caliper ≥ 3 mm) was determined.

Pinus ponderosa laws

Ponderosa pine seeds collected in Arizona were sized and soaked in water for 24 h before sowing on July 30, 1984 (Table 1). At the USFS Nursery in Albuquerque, NM seeds were sown with an Oyjord seeder at a target density of $430/m^2$. Thirty 0.36 m^2 plots were established. Seedlings were tagged as described above. Mortality was determined in December 1984. Seedlings were hand-lifted and measured in November 1985.

Simple linear regression was used to characterize the relationship between TOE and shoot fresh weight. A weighted regression was applied to the plot means to account for differences in sample size among emergence days.

Results

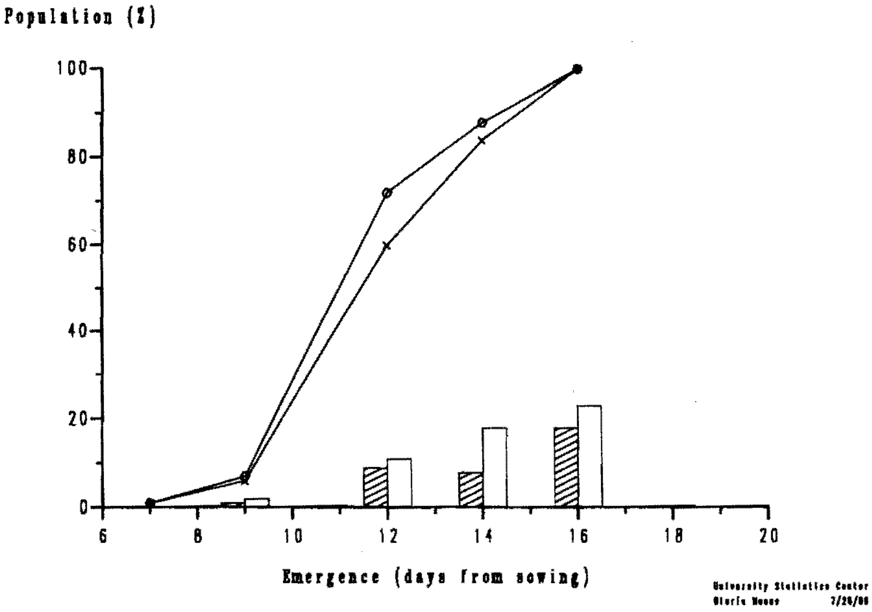
Emergence

Emergence at all three nurseries began 7-10 d after sowing, and was complete 20 d after sowing (Figs. 1a, b, c). Loblolly pine seedlings emerged most rapidly at the Oklahoma nursery, despite the brief stratification. The warmer soil associated with late sowing may have speeded emergence. There was little difference between seedlots sown at each nursery.

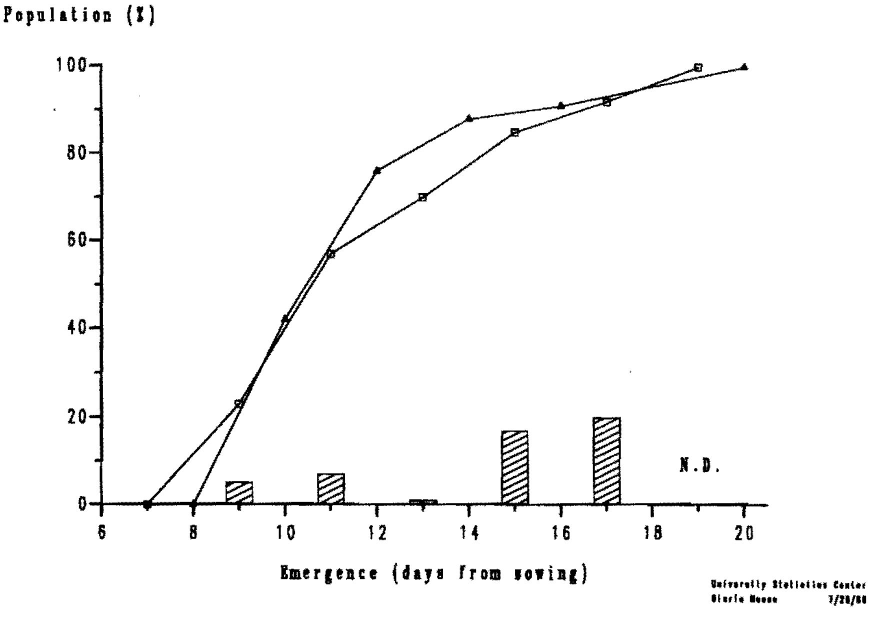
Mortality was negatively correlated ($a = .05$) with time of emergence (TOE). Loblolly pine mortality ranged from less than 1% for the earliest emergents to more than 20% for the late emergents. In the Albuquerque nursery, heavy rains 13 days after sowing increased early mortality. Nevertheless, ponderosa pine late emergents suffered the greatest mortality (Fig. 1c).

Ponderosa pine mortality 15 mo. after sowing was related to TOE as well. Total mortality for the first two emergence dates averaged 28% (Fig. 1c). Mortality for the later dates averaged 50%. Seedlings germinating on Day 14 had the highest total mortality (55%), suffering 12% early-season mortality and 43% over the following 11 months. In total, 43% of all seedlings died before lifting.

A


Population (%)
100
80
60
40
20
0
6
8
10
12
14
16
18
20
Emergence (days from sowing)

B


Population (%)
100
80
60
40
20
0
N.D.
6
8
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14
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20
Emergence (days from sowing)

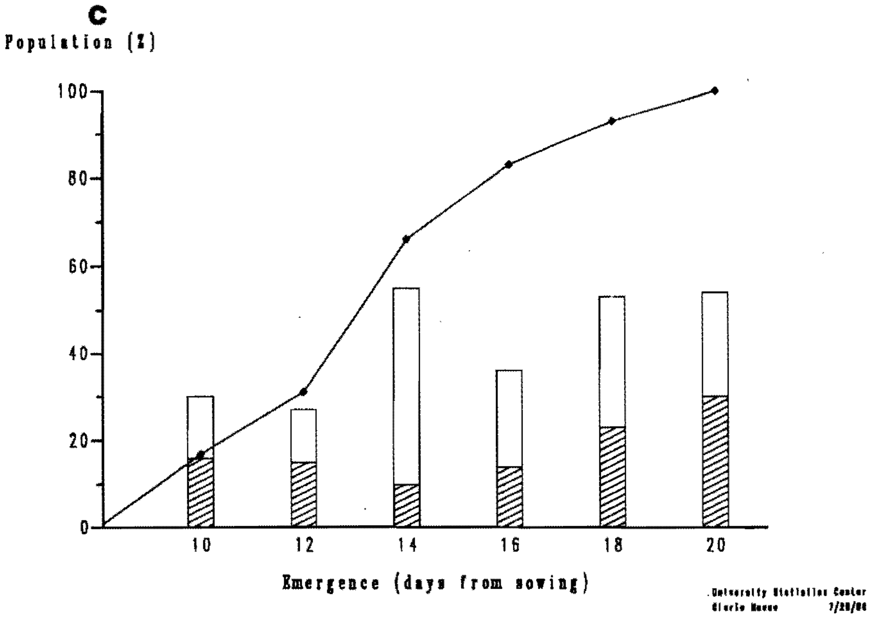

Fig. 1. Emergence patterns for A) two seedlots of loblolly pine at the Oklahoma nursery, B) two seedlots of loblolly pine at the Arkansas nursery, and C) ponderosa pine at the Albuquerque nursery. Open bars represent mortality at time of lifting. Closed bars for the Albuquerque represent mortality before December, 1984.

Morphology

TOE influenced all morphological parameters (Table 2), particularly shoot fresh weight. Height and caliper varied 15-30% from earliest to latest emergence dates; but shoot fresh weight varied up to 50%. Fresh weight is a function of both height and caliper. Therefore, discussion will be limited to the fresh weight response.

The relationship between shoot fresh weight and TOE was linear for both species (Fig. 2). One model fit the four loblolly pine seedlots. A separate model fit more closely the ponderosa pine data. Regardless of model, shoot fresh weight decreased 3.5% each day emergence was delayed. That is, over 10-d emergence period biomass decreased 35%. In each model. TOE accounted for over 80% of the variation in seedling fresh weight.

Yield or the proportion of seedlings meeting the grade specifications was also related to time of emergence (Fig. 3). For both loblolly and ponderosa pines, a minimum standard of caliper ≥ 3 mm was chosen. For ponderosa pine, acceptable caliper often exceeds 3 mm, but few seedlings in this study met a stricter standard. Therefore, the 3 mm standard was used for both species. Yield decreased 3.4%/d with delays in time of emergence (Fig. 3). However, if seedling mortality is included in the model, yield decreases 4.9% each day emergence is delayed (bold line).

Table 2. Seedling morphology related to time of emergence for loblolly pine and ponderosa pine. Values represent means ± 1 s.e.

Nursery	Seedlot	Days	Height	Caliper	Shoot F.W.	Diameter %≥3 mm
		from sowing	(mm)	(mm)	(g)	
Oklahoma	1	7	202±19	3.90±.61	13.83±3.09	75
		9	179± 7	3.61±.11	9.49±0.63	73
		12	171± 2	3.65±.09	8.92±1.18	72
		14	154± 2	3.45±.08	7.67±0.45	65
		16	147± 3	3.21±.25	5.69±0.23	47
		mean	164± 1	3.54±.07	8.21±0.66	67
Oklahoma	2	7	204±17	4.34±.39	11.16±2.01	82
		9	222± 8	4.16±.11	10.95±0.54	89
		12	198± 3	3.73±.03	7.88±0.14	77
		14	183± 4	3.45±.07	6.79±0.27	69
		16	175± 5	3.14±.08	5.91±0.28	56
		mean	195± 2	3.65±.03	7.72±0.12	74
Arkansas	1	10	183± 3	3.33±.05	8.56±2.00	67
		12	170± 2	3.43±.08	7.17±0.18	62
		14	159± 3	3.05±.06	5.83±0.22	47
		16	158± 6	3.00±.09	5.81±3.71	48
		20	159± 7	3.12±.16	6.29±0.68	47
		mean	166± 1	3.08±.03	6.73±0.28	60
Arkansas	2	9	208± 5	3.89±.11	8.96±0.19	72
		11	194± 2	3.79±.08	7.96±0.17	64
		13	168± 3	3.16±.06	6.34±0.22	55
		15	176± 3	3.25±.05	6.64±0.20	57
		17	162± 6	3.00±.09	5.23±0.27	45
		mean	188± 2	3.54±.04	7.55±0.10	62
Albuquerque		10	110± 1	3.56±.04	4.35±0.10	70
		12	109± 1	3.55±.04	4.40±0.12	70
		14	112± 1	3.61±.03	4.35±0.09	70
		16	99± 2	3.11±.94	3.04±0.08	50
		18	94± 2	2.81±.05	2.52±0.10	40
		20	90± 3	2.71±.06	2.17±0.13	30
		mean	106± 1	3.38±.02	3.85±0.05	64

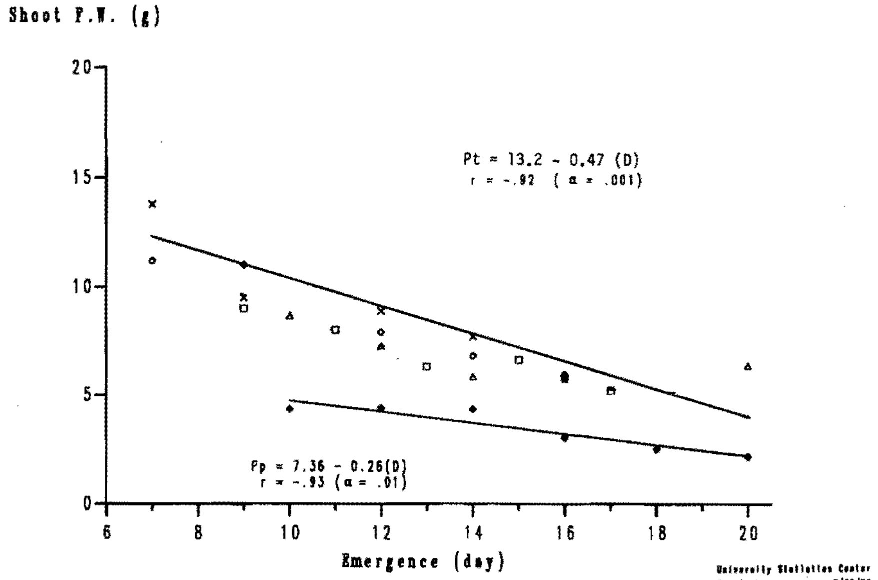

Fig. 2. Relationship between time of emergence and shoot fresh weight of loblolly pine at Oklahoma (x, o) and Arkansas (△, □) nurseries and ponderosa pine (◇) at Albuquerque nursery).

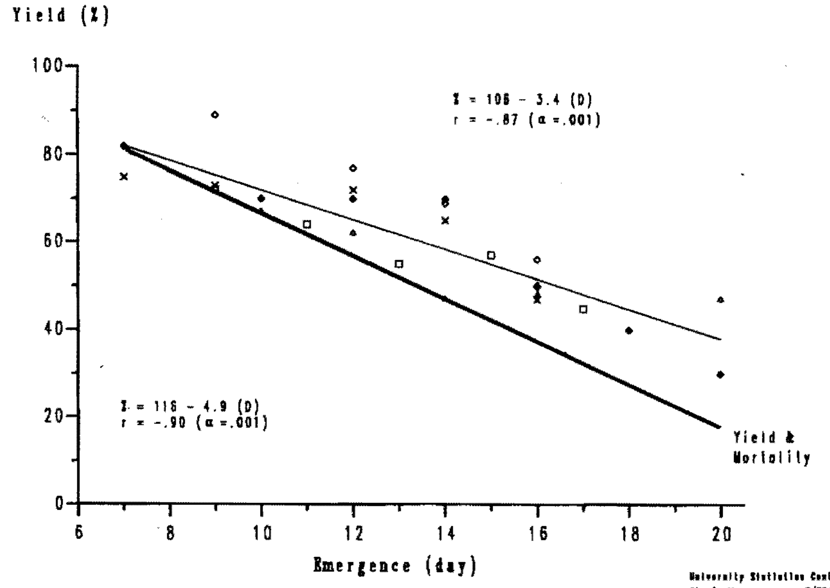

Fig. 3. Relationship between time of emergence and yield (% of population with caliper >3 mm) at Oklahoma (x, o), Arkansas (△, □), and Albuquerque (◇) nurseries. Bold line represent yield of emerging population (data not shown); fine line represents yield as a percent of surviving germinants.

Discussion

Seedling growth is governed principally by seed size, time of growth initiation or emergence, three-dimensional space available for growth and genetic components. Nursery practices can minimize the adverse effects independently associated with each of these factors. Less frequently, a single practice can mitigate effects derived from factor interactions. Seed size and genetic effects can be reduced simultaneously by careful sizing of seed and clonal sowing. However, clonal sowing does not eliminate time of emergence effects (Mexal & Fisher 1986). All seedlots used in this study were sized but were collected in natural stands from an undetermined number of parents.

Time of emergence had a profound effect on mortality of loblolly and ponderosa pine seedlings. Loblolly pine mortality ranged from less than 1% for the earliest emergents to as much as 23% for the late emergents. Ponderosa pine mortality ranged from less than 30% for early emergents to over 50% for late. Similar results have been reported for numerous annual plant species such as cocklebur (Zimmerman & Webb 1984), cotton (Wanjura & Minton 1981), *Rumex* (Wever & Cavers 1979), and *Impatiens* (Howell 1981). However, survival among annuals is sometimes negatively correlated with early emergence (Marks & Prince 1981). Late emergers may escape cold soils, exposure to inclement weather, or pathogens causing heavy mortality among early germinants.

The occurrence of pine seedling mortality over time was not recorded in this study. Therefore, it can not be stated unequivocally that mortality was competition induced. However, it is unlikely that ponderosa pine mortality before December 1984 was caused by competition. Five-month-old seedlings of ponderosa pine were less than 5 cm tall. Conceivably, competition caused the mortality occurring between December 1984 and November 1985, but dead seedlings were rarely harvested in any of the tests. This would indicate that seedlings were small and minimally affected by density dependent factors when lost.

Delayed emergence adversely affected all morphological parameters. Height decreased about 2%/day for all tests. Late emergence more severely reduced height growth of tobacco (Cundiff et al. 1978) and *Pinus caribaea* (Venator 1973). However, Boyer and others (1985) reported comparable reductions in loblolly pine caliper in response to delayed emergence. Seedling biomass was the growth parameter most affected by time of emergence. Shoot fresh weight decreased 3.5%/d. Among herbaceous plants, clover biomass decreased 8-10%/d (Black & Wilkinson 1963) and tobacco biomass declined 8%/day (Cundiff et al. 1978).

Several factors can modify the affects of delayed emergence on the genesis of size hierarchies. Tobacco plants located within the interior of the seedbed were more sensitive to emergence effects than were plants on the edge (Cundiff et al. 1978). Plant population density clearly influences emergence effects (Naylor 1980). Growth differences among early and late emergents of perennial rye grass decreased as population density increased. Factors affecting seed development within the maternal parent can also modify emergence effects. For example, Thomas & Raper (1979) found high nitrogen levels could reduce the variability in time of emergence. Waller (1985) found there was both a genetic and competitive component to the effects of time of emergence of *Impatiens*. With this species, both components were codominant.

Given the interactive effects of density dependent and genetic factors on growth, steps to improve uniformity must address both factors. Treatments to speed emergence might result in two responses. One model would suggest an increase in the speed of emergence with a concomittant increase in overall plant size. However, size hierarchies might not be eliminated. Taken to the extreme, variability would not be affected if all emergence occurred on one day. This is tantamount to sowing earlier (Mexal 1982, 1984). The increase in plant size results in a decrease in the percentage of cull seedlings. However, the smaller plants still may be at a competitive disadvantage in the nursery. These plants may not perform satisfactorily in the field despite meeting the minimum grading standards.

The second model assumes more rapid emergence will result in larger, more uniform seedlings. This model illustrates benefits gained from an earlier sowing date and more rapid emergence. Numerous studies support the view that the former model fits seedling responses to practices presently applied in pine nurseries. For example, extended stratification of loblolly pine seed improved speed of emergence and seedling caliper (Boyer et al. 1985) However, stratification did not significantly promote seedling uniformity. Evidence that the second model exists is scant.

This study empirically related the genesis of size hierarchies within seedbed populations to time of emergence. Rigorous nursery practices can minimize the effects of size hierarchy. However, it is not known if the hierarchy can be reduced or eliminated. The elimination of delayed emergence will improve seed efficiency and may improve seedling performance following outplanting. Seedling homogeneity will facilitate and improve the efficacy of crop treatments, particularly top and root pruning. Costs associated with reduction in time of emergence appear minor in view of potential economic benefits.

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