icantly better than controls, as were the cytokinins BA and 6-CP.

DISCUSSION

Considerable horticultural literature on chemicals shows antiabscission, antiethylene, and cytokinin activity in relation to reducing fruit drop and extending cut flower life. Boron as borax applied to soil prevented early fruit drop in chestnut (Park et al. 1978), Tordon inhibited stylar abscission in citrus (Einset et al. 1981), and coumarin inhibited coleus leaf abscission (Gupta 1970). In addition, cobalt chloride inhibited ethylene synthesis in bean and apple (Lau and Yang 1976); potassium permanganate, which oxidizes ethylene to water and carbon dioxide, increased storage life of pine seedlings (Barnett 1983); and 8-hydroxyquinoline, a powerful ethylene synthesis inhibitor, extended cut flower life (Parups and Peterson 1973).

CONCLUSIONS

It appears that abortion can be halved and seed yields more than doubled by spraying conelets once in early spring with cytokinins such as BA or CX, or with a number of antiethylene compounds, especially in combination with boric acid. Cytex and boric acid, unlike the antiethylene compounds proven effective previously (Hare 1981), are commercially available and relatively inexpensive. The next logical step would be pilot tests in longleaf pine seed orchards. □

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Nursery Seedbed Density Is Determined by Short-Term or Long-Term Objectives[1]

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*ABSTRACT. Lowering nursery seedbed density can increase the proportion of high-quality (grade 1 and 2) seedlings relative to cull (grade 3) seedlings. Outplanting higher grade seedlings can increase survival and volume production. Lowering seedbed density from present levels may therefore increase stand value at rotation age. The relationship between four seedbed density levels (60, 90, 120, and 150 seedlings/lineal bed foot) is evaluated for slash (*Pinus elliottii *Engelm.) and loblolly (*Pinus taeda *L.) pine, and the impact of grade on growth performance is projected. An economic analysis demonstrates how to determine the present value of the expenditure justified to alter seedbed density to obtain a projected future change in outplanting performance. Potential economic gains ranging from −$4.13 to $27.58 per thousand seedlings were derived by altering seedbed density from a base-level density of 120 seedlings/lineal bed foot. Positive values were associated with decreases in density and negative values with density increases. Site quality of outplanted areas plays a major role in determining the amount of the justifiable expenditure.*

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In forest nursery literature, economics is usually considered in the short term, meaning a yearly or seasonal basis (Hamner 1974, Shoulders 1961). This is because most nurseries are operated as cost centers within their organizations. For forest products firms this means that planting stock is transferred from the nursery to the land management division at production cost. State nurseries are similarly required to sell seedlings to the public at cost. A cost-

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center approach to nursery management usually places greater emphasis on minimizing the annual expenditure required to grow a specified number of plantable seedlings than on the long-term objective of optimizing the net economic benefits of the timber grown from those seedlings.

Despite a tendency to employ short-term economic considerations in nursery management, using long-term objectives to analyze expenditures for tree growing is not new. Most tree improvement programs, for example, were originally established on the premise that the discounted dollar value of increased product yields would exceed the costs of obtaining those increases. It has been repeatedly demonstrated that even small volume gains from tree breeding justify substantial investments in tree improvement (Davis 1967, Ledig and Porterfield 1981). Little comparable work exists in the area of nursery economics. This is interesting to note, particularly in light of evidence indicating a strong relationship between certain nursery practices, for example, seedbed density and fertilization and the growth performance of outplanted trees (Autry 1972, Switzer and Nelson 1963, Rowan 1986).

This paper considers some of the long-term economic aspects of nursery seedbed density for loblolly and slash pine and evaluates opportunities that may exist for altering seedbed density. Seedbed density is defined here as the total number of seedlings per lineal bed foot of seedbed, immediately prior to lifting (a lineal bed foot of nursery bed equals 4 square feet). Existing published and unpublished studies are employed to demonstrate how seedbed density and seedling grade are related, where grade is defined using the criteria outlined by Wakeley (1954). These grades are based primarily on seedling root-collar diameter. Grade 1 seedlings are those with a root diameter greater than 4.7 mm, grade 2's are those from 3.2 to 4.7 mm, and grade 3, or cull, seedlings, have a diameter less than 3.2 mm. Next, using one study by Blair and Cech (1974) for slash pine and another by South et al. (1985) for loblolly pine, the influence of grade on outplanting performance is evaluated. Outplanting performance is measured in terms of volume production and survival rates, at a given age. Finally, an economic analysis demonstrates how to determine the present value of the expenditure that is justified to change seedbed density for a projected future increase in stand growth.

The analysis does not suggest whether altering seedbed density is generally feasible for forest tree nurseries because data are not available to suggest how seedling production costs change with seedbed density. But given that nurseries are generally operated as cost centers with the objective of minimizing growing costs, current production costs are probably close to a minimum level. The analysis, therefore, conservatively assumes that any change in seedbed density will increase these costs, but no attempt is made to predict the magnitude of the increase.

SEEDLING GRADE AND SEEDBED DENSITY

The relationship between seedling grade and the number of seedlings grown per unit area of nursery bed is well documented (Burns and Brendemuehl 1971, Shoulders 1961). As seedbed density is reduced, holding other cultural practices constant, the proportion of grade 1 and 2 seedlings produced increases relative to grade 3 (cull) seedlings. Burns and Brendemuehl (1971) described this for slash pine in a Florida nursery, and the results of their study are depicted in Figure 1. A similar relationship for loblolly pine is shown in Figure 2, using data obtained from an unpublished study at Hammermill Corporation's Alabama nursery. Equations were fitted from these two studies in which the percentage of seedlings falling into a particular grade is described as a function of seedbed density (Table 1).

A telephone survey of six industrial nurseries in the South revealed that the reported seedbed density appears to be fairly uniform among companies, averaging 120 seedlings/lineal foot for both loblolly and slash pine. The nurseries also reported average cull percentages ranging from 5% to 10% of germinated seedlings But when southern pines are grown at seedbed densities greater than 100 seedlings/lineal foot, the production of culls can be much higher (Boyer and South 1986). In 35 studies with mycorrhizae in southern pine nurseries, only three had less than 10% culls in control (noninoculated) plots (Marx et al. 1984). Final seedbed density for loblolly pine seedlings exceeded 100/lineal foot in 85% of the studies, and the average cull percent in control plots was 21%. It is therefore likely that at current seedbed densities, many nurseries are producing and outplanting a high percentage of culls.

The equations in Table 1 are employed to evaluate the influence different seedbed densities have on the proportion of seedlings produced in each grade category. A total of four density levels are examined in the economic analysis. The base-level situation for each of the two species employs the standard practice average of 120 seedlings/lineal bed foot. Densities of 60, 90, and 150 seedlings/lineal bed foot are then compared to the base-level case The predicted percentage in each grade produced by these density levels appears in Table 2.

The analysis assumes that all grade 3 seedlings are culled, and the remaining grade 1 and 2 seedlings are in proportion to the total number of seedlings remaining. For example, for the slash pine base-level case (seedbed density of 120 seedlings per lineal foot), Table 2 shows that 30.9%, 58.0% and 11.1% grade 1, 2, and 3 seedlings will be produced. Removing the culls results in 35% grade 1

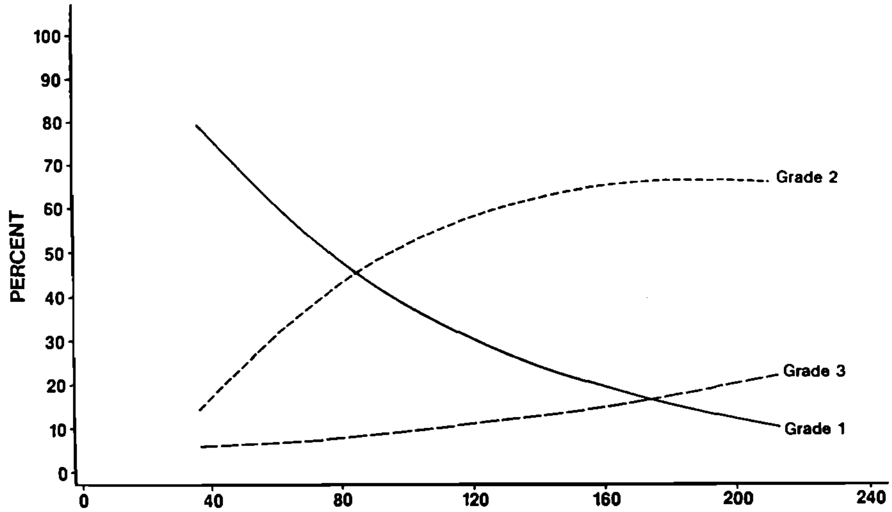

Figure 1. The percentage of slash pine seedlings produced in each grade is a function of nursery sowing density (Burns and Brendemuehl 1971).

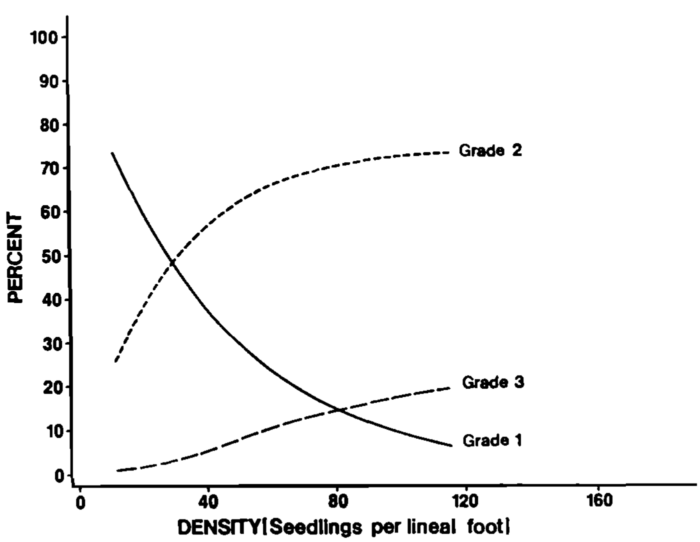

Figure 2. The percentage of loblolly pine seedlings produced in each grade is a function of nursery sowing density (Hammermill Corp., Unpubl. study).

seedlings and 65% grade 2 seedlings.

Table 2 shows that although the percentage of grade 1 and 2 seedlings decreases with increasing seedbed density, the total number of grade 2's produced per lineal foot of nursery bed increases with density. It might therefore be argued that seedlings should be grown at high densities and grade 3's culled, with grade 1's planted on company lands and grade 2's sold on the open market. This argument ignores the fact that for a given amount of seed sown, both poorer quality seedlings and fewer plantable seedlings will be produced. For example, at a density of 150 seedlings/lineal bed foot, 27.2% of the final crop (for loblolly pine) will be culled (Table 2). In a 20 million seedling nursery this would come to 5.44 million cull seedlings per year. This contrasts to a 9.9% cull loss (1.98 million seedlings) for a nursery with a seedbed density of 60/lineal bed foot. While the nursery with a lower density requires a greater total growing area, it would waste far less potentially valuable genetically improved seed.

There is a second reason that argues against growing seedlings at high densities. Not all seedlings of the same grade have the same morphology nor do they perform equally well. Outplanted Monterey pine (*Pinus radiata*) seedlings with 5 mm root collars grown at low densities grow better than 5 mm seedlings grown at high densities (Balneaves and Fredric 1983). The reasons for this improved performance are not known, but may be the result of an increase in seedling weight, better seedling nutrition, or better root systems for the seedlings grown at low densities. It has been documented that the root/shoot ratios of loblolly pine are better when grown at low densities (Shipman 1964, Harms and Langdon 1977, Rowan 1986, Nebgen and Meyer 1986). Under conditions of stress, survival and growth is better when loblolly pines have good root/shoot ratios (Mexal and Dougherty 1981, Auburn University 1984).

Table 1. Equations fitted to predict seedling grade by sowing density.

Slash pine[a]	
Percent Grade 1 = 121.4(exp(−0.0114*D*))	$r^2 = 0.971, n = 8$
Percent Grade 2 = 100 − (% Grade 1 + % Grade 3)	
Percent Grade 3 = 4.43(exp(0.00768*D*))	$r^2 = 0.899, n = 8$
Loblolly pine[b]	
Percent Grade 1 = 97.0(exp.(−0.0233*D*))	$r^2 = 0.749, n = 45$
Percent Grade 2 = 100 − (% Grade 1 + % Grade 3)	
Percent Grade 3 = 1.6 + 0.192*D*	$r^2 = 0.514, n = 45$
where: *D* = sowing density per four square feet (= 1 lineal ft)	

[a] From Burns and Brendemuehl 1971.
[b] Unpublished study, Hammermill Corporation, Selma, AL.

EFFECT OF GRADE ON OUTPLANTING PERFORMANCE

Many researchers have examined the influence of seedling grade on initial seedling survival

Table 2. Predicted seedling production in each grade, in percent and number of seedlings, for four sowing densities.[a]

Seedlings/ lineal foot	Slash pine grade[b] 1		2		3		Loblolly pine grade 1		2		3	
	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.
60	61.3	37	31.7	19	7.0	4	24.0	14	66.1	40	9.9	6
90	43.5	39	47.7	43	8.8	8	11.9	11	72.4	65	15.7	14
120[c]	30.9	37	58.0	70	11.1	13	5.9	7	72.7	87	21.4	26
150	22.0	33	64.0	96	14.0	21	2.9	4	69.9	105	27.2	41

[a] Calculations made using the equations shown in Table 1.
[b] A discussion of the grading criteria can be found in Wakeley (1954).
[c] Base-level case representing current standard nursery practice.

(1 to 5 years) following outplanting. A list of studies may be found in South et al. (1985). Most studies found that grade 1 seedlings survive better than grade 2 seedlings, which in turn survive better than grade 3 stock. Fewer long-term evaluations have been carried out, and results are not as consistent as the short-term studies. As Table 3 shows, however, several experiments maintained from 10 to 34 years indicate that both survival and volume growth are generally greater for large caliper seedlings (Blair and Cech 1974, South et al. 1985, Wakeley 1969).

Most experiments examining the effect of grade on tree survival and growth are biased relative to what would be observed in the field because they are outplanted by grade. Both of the studies used in the economic analysis were established with each seedling grade planted in separate plots. In an operational setting, however, different grades will be outplanted in about the same proportions at which they were raised in the nursery. The volume gains obtained will therefore be different from those observed from planting each grade separately, because a planted acre would consist of stock from two grade categories.

Lacking more complete data, it is assumed that per-acre volume production by grade equals that of the studies cited in Table 3, weighted by the proportion at which each grade is outplanted operationally. This assumption may be conservative since planting grades separately can mask growth differences (Pawsey 1972). Blair and Cech (1974) found that 34.2, 30.9, and 21.6 cords/ac were produced at age 13 by slash pine grown from grade 1, 2, and 3 seedlings, respectively (Table 3). If these were grown in the nursery at a density of 120 seedlings/lineal foot, and grade 3's were culled, per-acre volume production at age 13 would be calculated as a weighted average of the remaining grade 1 and grade 2 seedlings:

$$0.35(34.2) + 0.65(30.9) = 32.06 \text{ cords/ac}$$

Table 4 shows that the adjusted per-acre volume projections for nursery stock sown at densities of 60 and 90 seedlings/lineal bed foot are greater than those of the base-level case, for both species. Also, stock sown at 150 seedlings/lineal bed foot has a lower projected volume than the base-level case.

Table 3. Per-acre volume production and survival rates at age 13 from two outplanting studies.[a]

Study	Species	Site index (base 25)	Grade[b]	Cords/ac	% Survival
Blair & Cech (1974)	Slash	70	1	34.2	64
			2	30.9	62
			3	21.6	48
South et al. (1985)	Loblolly	94	1	70.0	89
			2	59.5	85
			3	56.2	78

[a] Outplanted at 680 trees/ac in both studies.
[b] Using Wakeley's (1954) criteria.

ECONOMIC ANALYSIS

The analysis assumes that the long-term objective is to maximize the discounted value of stumpage sales. Since both Blair and Cech's and South et al.'s studies deal with 13-year-old plantations, the discounting period is the same in each case. Also, as mentioned, both studies employed outplanting densities of 680 trees/ac. A 6% real discount rate is used, reflecting Nordhaus' (1974) finding that 6% represents the historical rate of return on corporate capital in the United States. A stumpage price of \$20/cord is used, which is representative of current pulpwood prices in southern markets.

Adjusted per-acre pulpwood volumes for each seedbed density and the present values corresponding to these volumes are shown in Table 4. Compared to the base-level situation, present value per acre is higher for low seedbed densities (60 and 90 seedlings/lineal bed foot) and lower for the high density case (150 seedlings/lineal bed foot). This indicates that opportunities may exist to lower nursery seedbed density from the currently employed average of 120 seedlings/lineal bed foot.

The present value of the justifiable expenditure per acre to alter seedbed density from the base-level density is calculated by subtracting the base-level present value in Table 4 from the present value of the altered density stand However, since nursery production costs are usually expressed in units of 1000 seedlings, the per-acre values must be multiplied by 1.47 (=1000/680). These results are shown in Table 5. Positive values indicate that money could be spent to lower seedbed density and negative figures indicate that raising seedbed density would incur a loss. Table 5 shows that even minor per-acre improve-

Table 4. **Adjusted per-acre volume production and present value of 13-year-old stands for four seedbed densities.**[a]

Nursery seedbed density (seedlings/lineal bed ft)	Slash pine (SI 70, Base 25) Vol/ac (cords)	Slash pine (SI 70, Base 25) Present value ($)	Loblolly pine (SI 94, Base 25) Vol/ac (cords)	Loblolly pine (SI 94, Base 25) Present value ($)
60	33.1 (3.1%)[c]	310.37	62.2 (3.3%)	583.24
90	32.5 (1.3%)	304.75	61.0 (1.3%)	571.98
120[b]	32.1	300.99	60.2	564.48
150	31.7 (−1.0%)	298.18	59.9 (−0.5%)	561.67

[a] Seedlings outplanted at 680 trees/ac, stumpage price of $20/cord, real discount rate of 6%, and discounting period of 13 yr.
[b] Base-level case.
[c] Percentage volume difference per ac from base-level case.

ments resulting from decreasing nursery seedbed density justify substantial expenditures. For example, lowering density from 120 to 90 increases projected slash pine volume by only 1.3%, but results in a justifiable expenditure of $5.88 per thousand seedlings, when outplanted on site index 70 (base 25) land. This represents a 32.7% increase over the $18/1000 average southern pine seedling production cost reported by Mills and South (1984). Lowering the density to 60 increases the additional amount that could be spent to $14/1000. Results are more pronounced for the higher site index land (Table 5).

The magnitude of the justifiable expenditure to lower seedbed density is better visualized on a whole nursery basis. A 15 million seedling slash pine nursery producing stock for planting on site index 70 land could spend an additional $206,850 to lower density from 120 to 60 seedlings/lineal bed foot. This corresponds to a per-acre projected volume increase of 3.1% (Table 4).

The values in Table 5 show that as site quality increases, the justifiable expenditure per thousand seedlings also increases. Although the studies evaluated are from two different species and therefore not directly comparable, the loblolly study was conducted on an extraordinarily productive site (site index 94, base 25) and produced approximately twice the volume of the slash pine study (site index 70, base 25). The justifiable expenditure in that case is therefore twice as great, because pulpwood prices, discount rate, and the discounting period are equal in each case.

The role site quality plays on the justifiable expenditure is generalized in Table 6. This shows how volume increases of 1 to 4% over a range of site productivity levels influence the amount that could be spent to obtain those increases. The values were calculated in the same manner as those in Table 5, except that site productivity is not annualized. Even on poor to average sites, volume increases as small as 1 to 2% justify relatively substantial investments. The $1.79/1000 seedlings that could be spent to increase the productivity of a 1 cord/ac/yr site by 1% represents almost a 10% increase over the current average seedling cost of $18/1000. On better sites, the amount that can be spent is much higher. The total justifiable expenditure for a particular organization thus represents a weighted average of site productivity, number of outplanted acres in each productivity class and expected volume gain.

Because site is so important in determining value, an organization carrying out a similar analysis must be very conscious of the conditions under which seedlings will be outplanted. Using long-term objectives to evaluate justifiable nursery costs therefore requires that nursery and outplanting practices be closely linked to one another. This is not consistent with the cost-center approach, which currently is the norm for most nursery operations.

The analysis presented is incomplete because it focuses on a single aspect of nursery management, assuming that all other practices remain constant. Sowing date, fertilization, and lifting date can all substantially affect the equations in Table 1, and these practices vary for each nursery. Also, only the revenue side of the picture has been examined because the production cost changes that would be incurred from changing seedbed density are not

Table 5. **Present value of expenditure justified to alter seedbed density from 120 seedlings/lineal foot to 60, 90, or 150 seedlings/lineal bed foot, per 1000 seedlings-grown.**[a]

Density changed to:	Slash pine (SI 70, Base 25)	Loblolly pine (SI 94, Base 25)
60	$13.79 (76.6%)[b]	27.58 (253.2%)
90	5.88 (32.7%)	11.03 (61.3%)
150	−4.13 (−22.9%)	−4.13 (−22.9%)

[a] Stumpage price of $20/cord, discount rate of 6%, discounting period of 13 yr.
[b] Percentage dollar change from average growing costs of $18/1000 seedlings reported by Mills and South 1984.

Table 6. **Additional justified expenditure, per 1000 seedlings, to obtain a volume increase at age 13, for sites of varying productivity.**[a]

Original site productivity (cords/ac/yr)	Percentage volume increase over original site productivity: 1%	2%	3%	4%
	Additional justified expenditure ($):			
1	1.79	3.58	5.37	7.16
2	3.58	7.16	10.75	14.33
3	5.37	10.75	16.13	21.51
4	7.16	14.33	21.51	28.67
5	8.96	17.92	26.88	35.84

[a] Stumpage price $20/cord, discount rate 6%, discounting period 13 yr, trees outplanted at 680 trees/ac.

yet known. An issue not even considered is that seedlings grown at low densities tend to have heavier tops and root masses, which would almost certainly drive up hand-planting costs. Finally, although growth projections are presented, these are very tentative. This type of analysis is useful, however, for identifying opportunities that may exist to increase plantation yields by reducing seedbed density, but this reduction is justifiable only when a long-term outlook is adopted by timber growers. □

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