Loblolly Pine Response to Bedding and Fertilization Varies by Drainage Class on Lower Atlantic Coastal Plain Sites

W. H. McKee, Jr. *and* **L. P. Wilhite,** *USDA Forest Service, Southeastern Forest Experiment Station, Charleston, SC 29407.*[1]

*ABSTRACT. Growth response of loblolly pine (*Pinus taeda *L.) to bedding and phosphorus fertilization was determined on three sites classified as moderately well, somewhat poorly, and poorly drained. Ten-year growth in terms of height and diameter showed a pronounced response to treatments on the poorly drained site but only a small response on the other sites on which competition was eliminated as a factor in all treatments.*

Bedding and fertilization interacted only on the poorly drained site where response to bedding was most pronounced. Our projection of height over age curves for individual treatments suggest that response to phosphorus alone may compare favorably with bedding plus phosphorus after the pines are about age 20 on the poorly drained site. Nutrient concentration in foliage alone was not indicative of the differential growth response to fertilizer obtained over drainage classes.

Bedding and phosphorus fertilization are prescribed by many forest managers responsible for regenerating loblolly pine (*Pinus taeda L.*) on lower Coastal Plain sites. A number of authors have reported dramatic growth responses to these treatments when applied alone or in combination. Also, prescriptive methods have been developed to determine which sites will respond to phosphorus based on soil tests or on foliage tests (Wells and Crutchfield 1969). Prescriptions for response to bedding have not been well defined, but obvious responses to bedding and to bedding plus phosphorus fertilization have been demonstrated. More recently, controlled physiological studies indicated that phosphorus fertilization may, in part, replace the need for drainage on some sites (McKee et al. 1984).

This report compares the response of loblolly pine to bedding and fertilization on three sites in drainage classes commonly encountered in the lower Atlantic Coastal Plain.

METHODS

Sites

On the Santee Experimental Forest and Francis Marion National Forest in South Carolina, three study areas were established that represented three drainage classes: (1) a moderately well-drained site (Goldsboro series), (2) a somewhat poorly drained site (Wahee series), and (3) a poorly drained site (Bladen series). Elevation of the sites ranged from 30 to 45 ft above sea level.

The soils of all three areas are acid, have internal drainage restrictions, and are low in fertility by agronomic standards. Their A horizons are only about 6 in thick, and most of their extractable nutrients and organic matter are within 4 in of the soil surface (Table 1). Subsurface material has less fertility, and the surface horizon is considered the primary source of nutrients for young pine.

The sites have never been under cultivation. The poorly drained site, a savannah, originally supported grasses and sedges and scattered pond pine (*P. serotina* Michx.) and sweetbay (*Magnolia virginiana* L.), whereas the two better drained sites supported merchantable stands of 50- to 70-year-old loblolly and longleaf pine (*P. palustris* Mill.) with dense hardwood understories.

Treatments

The entire regeneration operation was accomplished during 2 years prior to planting on each site, and consisted of broadcast burning, clearcutting stems more than 5-in dbh, a second broadcast burning, mechanical site preparation, treatment with herbicide, and planting.

Bedding on the poorly drained site consisted of constructing ridges wih repeated passes of a double-moldboard fireline plow The other two sites supported more shrubs and small trees, and this vegetation was sheared and rootraked into windrows for the bedded plots. Control plots (no

[1] W. H. McKee, Jr., is principal soil scientist and L. P. Wilhite, silviculturist, retired, USDA Forest Service, Southeastern Forest Experiment Station. This research was supported in part by W. R. Grace and Company, Memphis, Tennessee.

Table 1. Soil properties of three sites at the 0- to 4-in depth before site preparation, by drainage class, Francis Marion National Forest, SC.

Soil property	Moderately well drained	Somewhat poorly drained	Poorly drained
Sand (%)	83	48	35
Clay (%)	8	14	39
pH	4.92	4.83	4.48
Available phosphorus (ppm)	13.45	4.4	1.50
Exchangeable calcium (ppm)	152	372	96
Exchangeable magnesium (ppm)	25	50	52
Exchangeable potassium (ppm)	20	16	40
Total nitrogen (ppm)	1061	1423	1420
Organic matter (%)	4.43	7.85	8.97

treatment) were not sheared or rootraked. Beds on all three sites were 10 ft apart on centers, and settled from an initial height of 15–18 in to a rather stable height of about 12 in.

Shrubs and small trees on the control plots on all sites were felled with hand tools and left where they fell. To reduce the confounding effects of woody competition on the relationships among treatments, soil properties, and pine responses, competition on all plots was reduced to approximately the same low level by spraying the herbicide 2,4,5-T on the stumps of the hardwoods and shrubs.

The 1-0 loblolly seedlings were planted in February 1971 on the somewhat poorly drained site and 2 years later on the other two sites. Consequently, different weather conditions undoubtedly are responsible for some of the differences reported in the results and discussion of this paper. However, weather records through the first several years after planting do not appear to contain any departures from normal conditions great enough to significantly affect differences between the earlier and later plantings.

Analyses of soil and pine foliage samples collected during the first growing season indicated that phosphorus (P) and potassium (K) might be limiting. Consequently, fertilizer treatments for the ¼-ac subplots within each plot were randomly assigned the following: no fertilizer; P at the rate of 50 lb/ac applied as triple superphosphate (46% P_2O_5); K at the rate of 100 lb/ac applied as muriate of potash (60% K_2O); and the combination of P and K. These granular fertilizers were broadcast by hand at the beginning of the second growing season. At the beginning of the sixth growing season, nitrogen (N) at the rate of 200 lb/ac was hand broadcast as industrial urea prills (46% N) on all subplots that had previously been fertilized with P, K, or P and K.

Measurements, Sampling, and Analyses

Pine heights and survival were measured soon after planting, then annually through age 5, and again at ages 8 and 10. Dbh was measured at age 10.

At the end of the first growing season, ten soil cores were taken from each subplot at a depth of 0–4 in. Segments from the same depth were composited by subplots, dried, and crushed to pass a ten-mesh screen. Total nitrogen was determined by Kjeldahl analysis (Nelson and Sommers 1973), extractable phosphorus was determined with Bray P-2 extractant (Bray and Kurtz 1945), and exchangeable bases were extracted with *N* ammonium acetate (Jackson 1958). Soil pH was measured with a glass electrode in a 1:1 soil–water mixture, mechanical analysis was done by the Buoyoucos hydrometer method, and organic matter was determined by wet digestion.

At the end of each of the first five growing seasons, foliage from at least ten trees on each subplot was collected, dried for 24 hours at 70°C, and ground to pass a 40-mesh screen. One gram of plant material was dry-ashed at 450°C for 2 hours and taken up in 0.3 N nitric acid. Then phosphorus was determined by the molybdovanadate procedure.

Experimental Design and Analysis

One-acre rectangular bedded and control plots were established in randomized block designs consisting of three blocks on the poorly drained site and two blocks on each of the other two sites. Differences on blocking reflects space available and treatments applied on each site. Each plot contained four ¼-ac subplots that were randomly assigned fertilizer treatments. Each subplot contained 80 planting positions at 6 × 10 ft spacing in measurement plots surrounded by a border of one or two rows of isolation trees in the treatment plot.

The studies were analyzed individually by site with analysis of variance. The whole plot error was found to be less than subplot error, so error terms were pooled to conduct a Duncan's multiple range test. Differences were considered significant at the 0.05 level. Potassium did not improve growth on any site; thus, responses are pooled for potassium in fertilized and unfertilized treatments.

RESULTS

By the end of the tenth growing season, survival of loblolly as a response to bedding or fertilizer application showed responses of 7 to 18 percentage points between treatments, probably because herbicides had uniformly controlled woody competition (Table 2). On the moderately well-drained site, the fertilizer plus bedding treatment increased survival by 7 percentage points over the fertilizer alone treatment. Untreated or bedded plots were not different from the other treatments. Survival on the somewhat poorly drained site was increased by 19% with bedding. Fertilizer alone had no effect on survival. On the poorly drained site, fertilizer, bedding alone, or fertilizer plus bed-

Table 2. Average survival, diameter, and basal area at age 10 and foliar phosphorus levels at age 5 for loblolly pine planted on sites in three drainage classes on the Francis Marion National Forest, SC.

Treatments		Survival	Growth age 10		Foliage phosphorus
Bedding	Fertilizer	age 10 (%)	Average dbh (in)	Basal area (ft^2/ac)	concentration age 5 (%)
			Moderately well drained		
None	None	84AB	4.8B	83.8B	0.096A
	applied	78B	5.7AB	107.5AB	0.109A
Bedded	None	82AB	5.2AB	93.8AB	0.102A
	applied	85A	5.7A	112.9A	0.115A
			Somewhat poorly drained		
None	None	75B	4.8A	71.5B	0.086A
	applied	78B	5.2A	88.3AB	0.090A
Bedded	None	89A	4.9A	88.4AB	0.075A
	applied	93A	5.4A	111.8A	0.095A
			Poorly drained		
None	None	73B	1.6D	9.6D	0.063A
	applied	87A	4.0B	59.0B	0.097B
Bedded	None	84A	2.8C	31.2C	0.070A
	applied	87A	5.1A	95.5A	0.102B

Values within the same drainage class with the same letter are not significantly different at the 0.05 level.

ding increased survival by 15 to 19% over the control.

Height growth was increased by treatments on all sites (Figure 1). Fertilizer application and bedding were additive, and no significant interaction was found at the ages observed. On the moderately well-drained site, bedding with or without fertilizer increased tree heights by 33% 2 years after planting but increased height by only 7% 10 years after planting. On the somewhat poorly drained site, bedding with or without fertilizer improved tree heights 17 to 18% initially (age 2), but the bedding response decreased to 7% by age 10. On the poorly drained site, bedding with or without fertilizer increased tree heights at each measurement by 37 to 42% through age 10.

Application of phosphorus increased heights by 12% on the moderately well-drained site and 26% on the poorly drained site at age 2. By age 10 fertilization had improved heights by 10% on the moderately well-drained site. Fertilization including phosphorus increased heights by 95% at age 10 on the poorly drained site. Since nitrogen response is confounded with phosphorus, it is impossible to isolate effects of phosphorus alone. Observation of the height growth curves suggested that the application of nitrogen at the beginning of the sixth growing season had little effect on height based on growth trends.

Of special interest is height growth trends as related to age of tree and treatment where difference in height between treatments appear to narrow with time. For 5 to 7 years after planting, trees were taller on bedded-alone plots, after this, height growth was greater on fertilizer-alone plots. The relative response to bedding or fertilizer applied alone varied by site, with the response to fertilizer alone greater than that to bedding by age 6 on the poorly and somewhat poorly drained sites and by age 8 on the moderately well-drained site.

Average dbh was increased 0.67 in at age 10 by the addition of phosphorus at the beginning of the second growing season and of nitrogen at the beginning of the sixth growing season on the moderately well-drained site. On the somewhat poorly drained site, treatments had no effect on dbh, which averaged 5.09 in. Dbh was increased by 77% with bedding, 152% with nitrogen and phosphorus, and 225% with the combination of treatments on the poorly drained site. Thus, diameter growth response roughly parallels height growth for the applied treatments.

Basal area expressed on an acre basis showed a response to treatments similar to that of dbh, but also reflects the influence of the small changes in survival. The

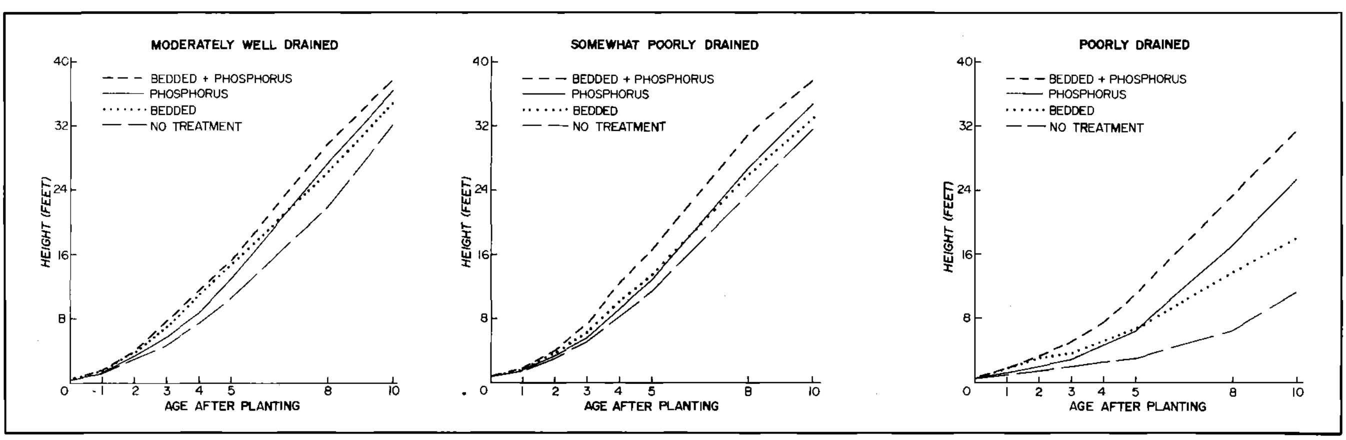

Figure 1. Height growth through age 10 of loblolly pine stands on sites in three drainage classes and with or without bedding and fertilization.

combination of bedding and fertilizer increased basal area by 35 to 36% on the moderately well and somewhat poorly drained sites. Basal area for sites treated by bedding or fertilization alone was not significantly different from that on other treatment sites. On the poorly drained site, basal area was increased by 21.6 ft^2 with bedding, 49.4 ft^2 with fertilizer, and 85.9 ft^2 by the combination of treatments.

Total volume of stem wood/ac showed trends similar to the other growth measurements (Figure 2). On the moderately well and somewhat poorly drained sites, total vol/ac of stem wood (outside bark) was increased 51 to 86% over the control with the combination of fertilizer and bedding. Either of these treatments applied alone did not significantly increase stem volume. Treatments had a dramatic effect on the poorly drained site where stem volume was increased by 3.2-fold with bedding, 9-fold with fertilizer, and 18.7-fold with the combination of fertilizer and bedding. On this site the bedding and fertilizer interacted to increase volume more than the additive effect of the bedding or fertilizer alone.

A significant response to treatment was found with foliage analysis: fertilization increased foliage phosphorus by 0.03 percentage points on the poorly drained site but not on the moderately well or somewhat poorly drained area. On the two better drained sites, the phosphorus application increased foliar phosphorus levels 0.01 to 0.02 percentage points. Phosphorus level in needles for fertilizer and unfertilized treatments tended to decrease with poorer drainage. Bedding appears to increase foliage phosphorus somewhat through improved drainage and/or added nutrients, but the effect was not significant.

The trend for phosphorus content of loblolly pine foliage to increase with improved drainage has been reported by White and Pritchett (1970) and McKee et al. (1984). McKee et al. also found that with flooding, phosphorus tended to accumulate in roots, which suggests a translocation problem in trees on flood sites. This observation suggests an explanation of the observed patterns and the need to consider drainage class or flooding status of trees with foliar phosphorus requirements to evaluate the need for and response to phosphorus on wet sites (Wells et al. 1973). A large number of sites would need to be sampled to substantiate this relationship.

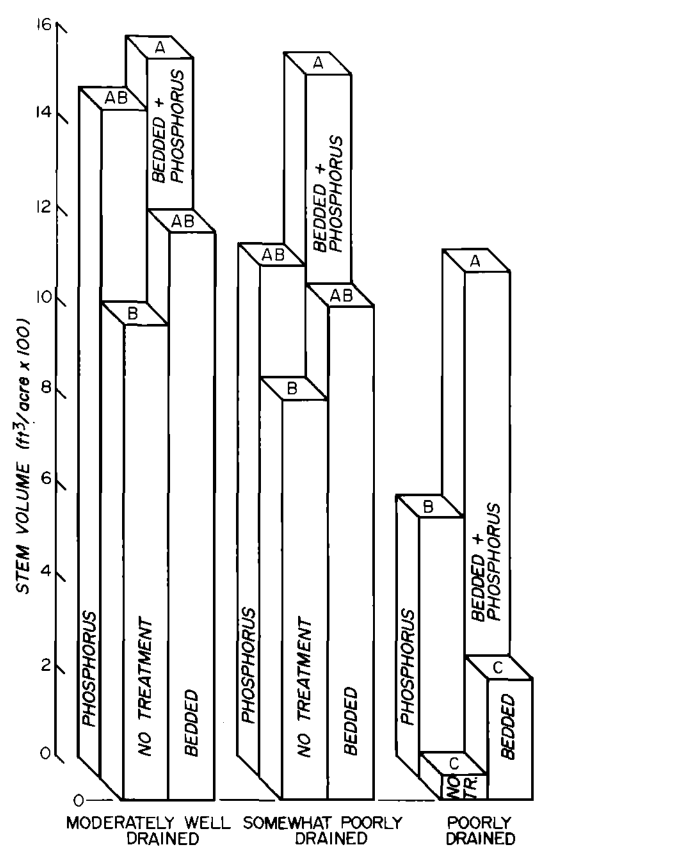

Figure 2. Vol/ac of stem wood (outside bark) of loblolly pine stands on sites in three drainage classes and with or without bedding and fertilization. Bars within drainage class with the same letter are not significantly different at the 0.05 level.

DISCUSSION

Under the conditions of this study, the main response to bedding is considered to be drainage since any competing hardwood vegetation was controlled with herbicide. In this respect Walker (1962) found that under controlled conditions loblolly pine responded positively to drainage at depths of 4 to 8 in. He concluded that drainage to 8 in was satisfactory for growth of young seedlings. Drainage by itself, however, will not always improve growth (Terry and Hughes 1975). In this respect, White and Pritchett (1970) found that loblolly seedlings up to age 5 on a site with water tables controlled at 18 in grew taller than those with a water table at 36 in. As further evidence Mann and McGilvary (1974) found that high beds constructed on dry to intermediate sites did not improve slash pine growth through age 8. However, Haines and Pritchett (1965) observed that the concentration of organic matter and nutrients in beds had a positive effect on growth of 1-yr-old slash pine growing on Leon fine sand in Florida. Pritchett and Comerford (1982) noted over a 20-yr period that slash pine growing on poorly drained sites—but not on sites with better drainage—responded to phosphorus and that growth was related to the amount of available phosphorus. A similar trend is found in our study where a greater increase in growth (height, diameter, volume) is found in response to phosphorus on sites with poorer drainage compared with sites with better drainage.

White and Pritchett (1970) observed that fertilization with 360 lb/ac of diammonium phosphate (76 lb of phosphorus/ac) would not adequately substitute for drainage in flatwood soils such as Leon fine sand for loblolly pine grown to age 5. Our study also showed that the addition of phosphorus did not improve height growth as much as bedding on the three sites to age 5, but between ages 6 and 8, trees on phosphorus-alone plots grew taller than trees on bedded-alone plots on all three sites. This change may be accounted for by the trees lowering the water table on the poorer drained plots through transpiration.

According to Langdon and Trousdell (1978) pine growing at a basal area of 40 ft^2/ac will lower the soil water table about 1 ft when the cumulative precipitation minus cumulative evaporation is a -10 in rainfall. Thus, when trees have reached a height of 10 to 20 ft, the effect of water loss from the stand would be expected to be about equal to that of the effect of bedding. This, in part, accounts for height growth at ages 5 to 7 resulting from treatment by phosphorus alone exceeding that resulting from bedding alone. Other factors affecting draw-down of soil moisture are the effect of accelerated growth of herbaceous weeds and grass due to the addition of phosphorus, which is suppressed as the stand begins to close, and the loss of the early advantage of improved nutrition found with the accumulation of topsoil in beds.

According to the observations of Hook et al. (1983), DeBell et al. (1984), and McKee et al. (1984), another factor affecting the response to phosphorus is that phosphorus changes the metabolic activity of loblolly pine roots under flooded conditions and improves their adaptability to flooding. As a projection of the height data, it appears that the trees treated with phosphorus alone will compare favorably with those treated with phosphorus plus bedding in 10 to 15 years. An indication of a continued response to phosphorus by loblolly pine at least through age 20 is reported by Tiarks and Shoulders (1982), who found that heights of loblolly pine were related to phosphorus content of foliage and depth to mottling. Extractable phosphorus in the soil was a poorer indicator of height growth in their work.

The duration of a response to phosphorus fertilizer is open to conjecture; however, if the long-term response patterns reported by Pritchett and Comerford (1982) for slash pine are an indication of what can be expected with loblolly pine, the one application of phosphorus should be adequate for at least a 20-yr timber rotation.

The present study indicated that additional criteria for evaluating soils for phosphorus fertilization are needed. Drainage or perhaps depth to mottling or water table as used by Tiarks and Shoulders (1982) might be useful in helping to establish critical foliage phosphorus level for phosphorus additions. In this respect, a soil grouping as established for slash pine by Pritchett and Gooding (1975) might be useful.

SUMMARY AND IMPLICATIONS

Over a 10-yr period, loblolly pine growing on moderately well to poorly drained sites appears to be more responsive to phosphorus applications than mechanical bedding treatments. An interaction between bedding and phosphorus treatment occurred only on the poorly drained site. An important restraint in the application of these findings is that all hardwood competition was killed on both control and bedded plots at the beginning of the study. Thus, the beneficial effect of bedding on control of competition as it might alter survival and establishment of a uniform stand is not considered, only the effect on soil nutrition and drainage. On the poorly drained sites, fertilization and bedding appeared to improve survival.

If trees are to be grown for a saw-log rotation (30–50 yr) the response to bedding appears questionable on moderately well and somewhat poorly drained sites if competition is not a problem, because tree heights on plots with fertilization alone have surpassed the bedded treatment on all three sites, and as a projection, appear to be gaining on the combined treatments of bedding and fertilization. Future measurements will indicate if early height gains are diminishing with time.

Another factor is that phosphorus can generally be applied for less than one-fourth the cost of bedding at current prices. On a long-term basis, the results to date indicate fertilization (namely phosphorus) can replace bedding as a drainage treatment for loblolly pine, supporting the hypothesis of Langdon and McKee (1981).

The foliage analysis indicates that the relationship of the amount of phosphorus in foliage with expected growth response to phosphorus fertilization could be improved if a measure of drainage was included in the prediction.[2] □

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[2] *NOTE:* This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and federal agencies before they can be recommended.

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Survival and Growth of Outplanted Pine Seedlings After Mycorrhizae Were Inhibited by Use of Triadimefon in the Nursery

S. J. Rowan, *Southeastern Forest Experiment Station, USDA Forest Service, Carleton St., Athens GA 30602 and* **W. D. Kelley,** *Auburn University Agricultural Experiment Station, Auburn, AL.*[1]

ABSTRACT. Triadimefon (Bayleton®), applied as foliar sprays at recommended and higher rates to pine seedlings in nursery beds, inhibited development of mycorrhizal roots, but subsequent survival percentages and rates of growth of the seedlings in plantations were not affected.

During the past 2 years considerable attention has been directed toward determining whether triadimefon (Bayleton®) applied to pine nurseries for control of fusiform rust inhibits development of ectomycorrhizae. It was reported recently (Cordell and Marx 1984) that three or four foliar sprays of triadimefon at a rate of 8 oz active ingredient (ai)/ac/application (appl) sharply inhibited development of ectomycorrhizae by both artificially introduced (*Pisolithus tinctorius* [Pers.] Coker & Couch)

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