Loblolly Pine—Pushing the Limits of Growth

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ABSTRACT: *With mean annual increments up to 5.4 cords/ac/yr, six loblolly pine (*Pinus taeda *L.) research sites in Georgia produced yields on par with other results from intensively managed loblolly plantations around the world. Cultural treatments in the Georgia study include complete control of vegetation other than the planted pines with multiple applications of herbicide, annual fertilization, the combination of complete vegetation control and annual fertilization, and an intensive mechanical site preparation treatment. Complete vegetation control resulted in higher yield production at ages 10 to 12 yr than the intensive mechanical treatment at all locations. This regime also resulted in higher yield production than the annual fertilization treatment at four of six locations. Volume mean annual increment for 10- to 12-yr-old plantations with the combination treatment of complete vegetation control and annual fertilization ranged from 325 to 490 ft^3/ac, growth rates comparable to those obtained at other high biomass production areas throughout the world. Our economic evaluation based on these results shows that 8 to 12% real rates of return are feasible from investments in intensive loblolly pine plantations in the southeastern United States. South. J. Appl. For. 25(2):69–74.*

Key Words: Vegetation control, fertilization, intensive management.

Many theories attempt to explain why pines native to the southeastern United States exhibit radically greater growth rates when planted in other parts of the world. Factors that possibly affect these dramatic growth differences include climate and basal area carrying capacity (DeBell et al. 1989). Furthermore, southern yellow pines growing in exotic locations may enjoy complete freedom from their natural enemies such as native fungi and insects. These factors probably explain part of the differences that have been observed over the years. However, some component of these dramatic differences in growth rates is surely due to silvicultural practices employed. In fact, foresters routinely apply very intensive cultural practices for the management of plantation-grown loblolly (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm.) in Brazil, South Africa, and other locales associated with dramatically high growth rates. Routine management practices in many areas of the world call for very intensive site preparation, similar to that used for agricultural fields, followed by such treatments as fertilization, mechanical or chemical weed control, and mechanical cultivation during the rotation (Evans 1992).

Over the past 20 yr, several researchers have reported large gains in growth due to control of competing vegetation in pine plantations in the southeastern United States. (Miller et al. 1991, Pienaar and Shiver 1993, Swindel et al. 1988). Response magnitudes vary from study to study; however, mean annual increments as high as 225 ft^3/ac have been reported for stands that receive complete vegetation control. Fertilization at time of planting or at midrotation has shown great promise as a method of increasing growth (Allen 1987, Gent et al. 1986, Stearns-Smith et al. 1992). Of course, response to fertilization varies by site and type of fertilization regime used. Consequently, the range of reported responses extends from none to an additional 80 to 100 ft^3/ac/yr more than comparable unfertilized stands. In some of our own studies and experiences, we have even seen less net growth in fertilized plots when compared with similar unfertilized plots. Another contributing factor, genetic improvement, also results in growth gains (Cornelius 1994, Hodge et al. 1989, Talbert et al. 1985). Seedling quality and planting method influence growth too (Wakeley 1969, South 1993). Regardless of all of this evidence, a general perception seems to prevail that southern yellow pines cannot realize growth rates in their native habitat that approach their growth rates in other parts of the world. Below we present original results showing that intensive management practices can produce growth rates for loblolly pine in the southeastern United States comparable to growth rates for this species in other parts of the world. Such practices include improved genetic stock, thorough site preparation, control of unwanted vegetation, and fertilization.

Data

Our data come from a long-term growth monitoring study that we started in 1987. We designed the study to obtain

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growth data under carefully controlled conditions for loblolly pine plantations managed at varying levels of intensity. For the work reported here, we used data from six replicated complete-block designs at four locations throughout the state of Georgia. Using 3/8 ac plots, we applied the following treatments:

H Herbicide used to control all herbaceous and woody competing vegetation throughout the life of the study

F Fertilize as follows: First two growing seasons—250 lb/ac DAP plus 100 lb/ac KCl in the spring and 50 lb/ac of ammonium nitrate midsummer. During each subsequent growing season—150 lb/ac ammonium nitrate early- to mid-spring

HF Both H and F treatments

C Control treatment—no other treatment following intensive mechanical site preparation

We installed the study on recently cutover forestland (i.e., no old fields were used) and hand planted 1-0 improved loblolly pine seedlings at the equivalent of 680 trees/ac. At each location a single half-sib open pollinated family was planted. The genetically improved seed was obtained from crosses carried out by the North Carolina State University Tree Improvement Cooperative, and all seedlings were produced at the Union Camp Corporation nursery near Bellville, GA. We intended for our herbicide treatment to control all vegetation other than the planted pines during the study so that the pines would grow free of competition throughout their lives. In the early spring of years 1, 2 and 3, we evenly broadcast 4 oz/ac of sulfomethuron methyl (Oust®) over the site using a four-wheel all-terrain vehicle. Followup treatments with directed sprays of glyphosate occurred in midsummer of each year. After the third year, the crowns of the pines had closed, and we then limited additional herbicide treatments to sporadic use of directed sprays of glyphosate. All fertilizer applications were broadcast over the site by hand, using a cyclone spreader. All four treatments may be considered somewhat intensive as compared to the typical contemporary pine plantation. Even the "control" treatment consisted of an intensive mechanical site preparation. Site preparation, described below for each location, varied somewhat from location to location.

The oldest trees in our study were planted in the lower Coastal Plain near Waycross, Georgia, during winter 1987. Seedlings for this location are from half-sib family 7-56. For this location we have 12 yr measurements available. There are actually two installations of the study at the Waycross location. One installation we refer to as "Waycross wet," because the site experiences standing water during the winter and early spring of each year. The other installation we call "Waycross dry," because it does not typically experience standing water at any time during the year. At both of these installations the control treatment included an intensive bedding operation resulting in well-defined beds that were free of vegetation when we planted.

We established our third installation, on which we have age 11 measurements, in the upper Coastal Plain near Tifton, Georgia, in 1988. The half-sib 7-56 family was also used here. The control treatment at Tifton includes a bedding operation similar to that used at the two Waycross installations. We established two installations in the Piedmont near Eatonton, Georgia, in 1988. We referred to these two Eatonton installations as the "powerline site" and the "monitor site." We have 11 yr data for them. In 1989, we planted another Piedmont installation near Athens, Georgia, for which we will report 10 yr results. For all three Piedmont installations, the control treatment consisted of a shear, rake, pile, and disc mechanical treatment producing a very clean, tilled site. The seedlings used for the Piedmont installations are from the half-sib family 10-25.

Each installation consists of two complete blocks composed of four plots each with the four treatments assigned to the plots in a completely random manner within a block. Within each 3/8 ac treatment plot we established an interior 1/8 ac measurement plot and identified all the trees on this plot with a unique number. We measured these numbered trees annually for total height and height to live crown. In addition, we measured basal diameter on all trees less than 4.5 ft in height and dbh on all trees greater than or equal to 4.5 ft in height.

Soil profile examinations revealed typical eroded soils found in the Piedmont of Georgia at the installations near Athens and Eatonton. Specifically, at Athens the soil series consist of Pacolet, Cecil, and Madison. At the Eatonton installation, referred to as the "powerline site," the primary soil series is Cecil. However, the Eatonton installation, known as the "monitor site," the soils contain more variable soils consisting of the Cecil, Pacolet, Appling, and Davidson series. The installation near Tifton contained both Tifton and Pelham soil series. The Waycross "dry site" was comprised primarily of the Bonifay soil series. The Waycross "wet site" contained both Pelham and Rigdon soil series.

Results and Discussion

Growth Response

Treatment responses for dominant height (ft), average diameter at breast height (in.), stand basal area (ft^2/ac), stand merchantable volume (ft^3/ac) (volume of all trees with dbh at least 4.5 in. to a top diameter limit of 2 in. ob), and surviving stems/ac at each location (Tables 1–6) show that more intensively managed treatment plots grew at faster rates than less intensively managed treatment plots. Note that all differences discussed below were statistically significant at the 5% level unless otherwise noted. Merchantable volumes were calculated with individual tree volume equations developed by Pienaar et al. (1987). At all locations except the Waycross sites, the effect of removing competing vegetation (H treatment) significantly exceeded the effect of the fertilization regime (F treatment). However, at the Tifton site average diameter for the fertilization treatment exceeded the average diameter for the herbicide treatment. This difference in average diameter mostly results from excessive mortality on the fertilization plots producing an average density of 300 stems/ac as compared to 620 stems/ac for the herbicide only

Table 1. Average tree size and stand production levels for 10-yr-old loblolly pine plantation plots located near Athens, Georgia.

Treatment	Dominant height (ft)	Quadratic dbh (in.)	Basal area (ft^2/ac)	Volume (ft^3/ac)	Stems/ac
C	38.5	5.5	99.3	1,648	596
F	40.5	6.4	100.9	1,773	452
H	46.0	6.5	132.3	2,752	568
HF	49.0	7.2	164.8	3,623	580

Table 2. Average tree size and stand production levels for 11-yr-old loblolly pine plantation plots located near Eatonton, Georgia ("powerline" site).

Treatment	Dominant height (ft)	Quadratic dbh (in.)	Basal area (ft^2/ac)	Volume (ft^3/ac)	Stems/ac
C	40.6	5.1	89.8	1,461	636
F	47.4	6.3	118.6	2,489	548
H	49.3	6.2	129.0	2,877	624
HF	54.8	7.2	159.0	3,879	556

Table 3. Average tree size and stand production levels for 11-yr-old loblolly pine plantation plots located near Eatonton, Georgia ("monitor" site).

Treatment	Dominant height (ft)	Quadratic dbh (in.)	Basal area (ft^2/ac)	Volume (ft^3/ac)	Stems/ac
C	39.8	5.1	89.9	1,423	640
F	46.3	6.3	124.9	2,543	572
H	50.5	6.6	141.0	3,159	600
HF	53.4	7.1	153.5	3,571	556

Table 4. Average tree size and stand production levels for 11-yr-old loblolly pine plantation plots located near Tifton, Georgia.

Treatment	Dominant height (ft)	Quadratic dbh (in.)	Basal area (ft^2/ac)	Volume (ft^3/ac)	Stems/ac
C	47.5	6.3	120.9	2,722	556
F	47.8	8.7	124.7	2,773	300
H	53.5	6.6	149.1	3,738	620
HF	53.1	7.7	152.0	3,696	476

Table 5. Average tree size and stand production levels for 12-yr-old loblolly pine plantation plots located near Waycross, Georgia ("dry" site).

Treatment	Dominant height (ft)	Quadratic dbh (in.)	Basal area (ft^2/ac)	Volume (ft^3/ac)	Stems/ac
C	49.4	5.5	97.1	1,915	580
F	64.7	7.4	172.0	5,018	572
H	54.6	6.3	135.6	3,229	624
HF	60.9	7.3	184.1	4,994	628

Table 6. Average tree size and stand production levels for 12-yr-old loblolly pine plantation plots located near Waycross, Georgia ("wet" site).

Treatment	Dominant height (ft)	Quadratic dbh (in.)	Basal area (ft^2/ac)	Volume (ft^3/ac)	Stems/ac
C	47.5	5.0	91.6	1,562	672
F	62.7	7.4	189.0	5,284	640
H	50.0	5.8	125.0	2,656	672
HF	67.3	7.6	192.2	5,886	616

Table 7. Comparison of mean annual increments (ft^3/ac/yr and cords/ac/yr*) for the HF treatment (herbicide and fertilization) of loblolly pine plantations at six locations in Georgia.

Installation	Age	MAI (ft^3/ac/yr)	MAI (cords/ac/yr)
Athens	10	362.3	4.0
Eatonton—powerline	11	352.6	3.9
Eatonton—monitor	11	324.6	3.6
Tifton	11	336.0	3.7
Waycross—dry site	12	416.2	4.6
Waycross—wet site	12	490.5	5.4

* Assuming 90 ft^3 of wood and bark per cord.

plots. Magnitude of response at the Waycross sites was greater for the fertilization treatment than for the herbicide treatment. As a contrast, the fertilization treatment at Tifton resulted in tremendously increased levels of competing vegetation, which ultimately resulted in increased pine mortality. However, at the Waycross locations, fertilization not only increased the amount of competing vegetation but also increased pine growth over and above that observed on vegetation control plots (H treatment).

The most intensive treatment, the combination of fertilization and vegetation control (HF), resulted in the largest individual trees as well as the largest stand basal area and stand volume at all locations except the Waycross "dry" site and the Tifton site. Clearly, with the combination of vegetation control and fertilization, foresters hold the key to across the board gains in fiber production in loblolly pine plantations.

One of the major objectives of this study included the creation of a series of field plots established at the same point in time but growing at different rates. In order to exaggerate these differences in growth, we chose a wide range in intensity of silvicultural regime. Operational usefulness of the treatments was not a consideration. Yearly fertilization, a treatment not commonly practiced, may or may not be necessary to achieve growth rates similar to those shown above. Regardless, mean annual increment of cubic foot volume for the most intensive treatment (HF) at the six locations described above ranges from 3.6 cords/ac at the Eatonton "monitor" site to 5.4 cords/ac at the Waycross "wet" site (Table 7). Comparisons of these production rates with rates experienced elsewhere in the world clearly support a conclusion that cultural treatments account for a large proportion of the differences in production thus far reported for loblolly pine grown in exotic locations (Table 8).

Table 8. Comparison of mean annual increments (MAI) in total volume (ft^3/ac) for loblolly pine (*Pinus taeda* L.) plantations grown at various locations throughout the world. Bold type indicates sites from the Georgia study reported on herein.

Location	MAI (ft^3/ac/yr)	Rotation (yr)
South Africa*	523	22
Waycross, GA	**490**	**12**
Brazil*	442	8
Waycross, GA	**416**	**12**
Australia*	382	16
Hawaii†	371	11
Athens, GA	**362**	**10**
Eatonton, GA	**353**	**11**
S. Carolina†	352	11
Tifton, GA	**336**	**11**
Eatonton, GA	**325**	**11**

* From Evans (1992).
† From Burns and Hu (1983).

Thompson (1998) indicates that the average site for loblolly pine in Georgia produces around 1.0 to 1.5 cords/ac/yr under conventional plantation silviculture. Our intensive plantation silviculture study produced rates two to four times greater. In fact, our research shows that loblolly pine grown in the southeastern United States can produce yields comparable to those reported for this species when it is grown in exotic locations. Our results further verify that intensive silviculture, consisting of complete control of competing vegetation and yearly fertilization, produces these astoundingly high growth rates.

Growth Trend

By ages 10 to 12 in our studies, no abatement in growth rate is evident for the most intensive treatment (HF) at any of our installations. To illustrate this, we chose the Eatonton Powerline Site as a typical case. For this installation, the volume yield curve continues at a very steep slope at age 11 (Figure 1) for the HF treatment, while the curve for the mechanical site preparation treatment (C) appears to be flattening out. Recent measurements up through ages 11 to 13 not available in time to be included here lend further support to this trend. No decline in volume MAI is evident for the HF treatment. We believe that 3 cords/ac/yr and greater on a 13- to 15-yr rotation can certainly be achieved on the majority of sites where loblolly pine plantations are grown in the southeastern United States.

Economic Analysis

Clearly, current production rates for typical loblolly pine plantations grown in the southeastern United States fall far short of their potential. Our results show the possibility of dramatic increases. Forestry consists of combining biology and economics into an efficient business enterprise. Thus, one must address the issue of economic feasibility regarding increasing growth rates on these orders of magnitude. As mentioned above, we never intended to simulate operational procedures in our research study. However, several industrial organizations currently approach complete competition control on an

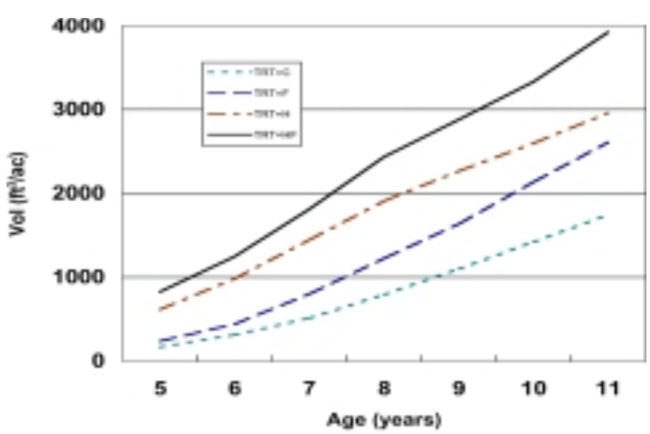

Figure 1. Merchantable volume development (ft^3/ac) through age 11 for the Eatonton, GA, powerline site for all four treatments (C = control, H = complete vegetation control with herbicide, F = annual fertilization treatment, HF = both H and F treatments)

Table 9. Approximate costs of various management activities for an intensively managed loblolly pine plantation grown in Georgia.

Year	Activity	Cost ($/ac)
0	Intensive site preparation	200
1	Planting and seedlings	70
1	Herbaceous weed control	60
2	Fertilization	60
2	Herbaceous weed control	60
6	Fertilization	75
10	Fertilization	75
14	Harvest	

operational scale in their silvicultural practices. Fertilization regimes calling for more than one application during a rotation are also becoming common. When growth rates such as those in our study occur in areas with high pulpwood values, such silvicultural regimes may not only be practical but also economically advantageous. Based on the data shown above, intensively managed stands should produce significant amounts of fiber as early as 12 to 14 yr of age. Current fiber rotation lengths of 18 to 25 yr can realistically be reduced to 12 to 15 yr, while doubling or tripling production on a given acre of ground. In the face of urban expansion and environmental pressure to reduce the numbers of acres dedicated to plantation forestry, this doubling and tripling of production may well be necessary to maintain fiber supplies.

To look at the economics of intensive management treatments as discussed above, we evaluate a management scenario which results in one of three possible yields (pessimistic, average, optimistic). The pessimistic yield assumption is 4000 ft^3/ac at age 14 (approximately 44 cords/ac or a MAI of 3.2 cords/ac/yr assuming approximately 90 ft^3 of wood and bark/cord). The average yield assumption is 4750 ft^3/ac at age 14 (approximately 53 cords/ac or MAI of 3.8 cords/ac/yr). The optimistic yield assumption is 5500 ft^3/ac at age 14 (approximately 61 cords/ac or MAI of 4.4 cords/ac/yr). These yields may seem high when compared to stands that have been managed without intensive treatments. However, our data show that these yields are quite realistic when plantations are managed very intensively. The management scenario to be evaluated consists of a very intensive site preparation treatment including a combination of mechanical and chemical treatments appropriate for the site. As was the case in our study, we assume that 680 trees/ac are planted. During the first and second growing seasons, herbaceous weed control (chemical) will be carried out. In years 2, 6, and 10, additional fertilization will be done. The specifics of fertilization treatments are not prescribed here since they will undoubtedly differ by site. Harvesting will occur in year 14, producing one of the three yields described above.

We are not suggesting that this management scenario is optimal or even that it is reasonable. We simply put it forward as one alternative that could be used to obtain growth rates of over 3 cords/ac/yr. Results from our study, as well as other results cited, suggest this to be a reasonable growth rate to expect on many sites.

The costs we have chosen (Table 9) may differ from current actual operational costs. In fact, we believe that they are high for most areas in the southeastern United States.

Table 10. Bare land value (BLV, $/ac using an uninflated discount rate of 7%) and real internal rate of return (IRR) for three yield scenarios and three stumpage values for intensively managed loblolly pine plantations grown in Georgia and harvested for pulpwood at age 14.

	Yield Scenario					
	Pessimistic		Average		Optimistic	
Stumpage ($/cord)	BLV ($/ac)	IRR (%)	BLV ($/ac)	IRR (%)	BLV ($/ac)	IRR (%)
40	116	7.9	444	9.5	547	10.7
45	255	9.0	512	10.6	740	11.8
50	395	9.9	680	11.5	933	12.7

However, we hope to illustrate that even if faced with significant costs throughout the rotation, intensive pine plantation management can produce competitive rates of return.

We calculated the internal rate of return (IRR, real uninflated rate) and bare land value (BLV) for the above management scenario with each yield scenario assuming that all volume sells as pulpwood. We applied three stumpage rates ($40, $45 and $50/cord) and assumed that annual taxes and administration costs total $7/ac. BLV values reflect an uninflated discount rate of 7%.

BLV ranges from a low of $116/ac for the lowest production/lowest stumpage combination to $933/ac for the highest production/highest stumpage combination (Table 10). Real IRR ranges from 7.9% to 12.7% for this range of treatment/stumpage combinations. Clearly, this analysis provides economic justification for intensive plantation management of loblolly pine in the southeastern United States with the achievement of mean annual increments of 3 or more cords/ac. Such production levels, and even greater ones, resulted from our study of intensively managed loblolly pine plantations.

Conclusion

Current growth rates of loblolly pine plantations in the southeastern United States fall short of their potentials. Our data indicate that loblolly pine grown in the southeastern United States can produce as much or more per unit area than production levels achieved in other high production areas in various parts of the world. Furthermore, our followup analysis shows that economically attractive returns will result for appropriate investments in the required intensive management regimes. As the available land base for timber production continues to decline from pressures such as environmental concerns and urban expansion, intensive management to maintain productive capacity seems more and more attractive.

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