THE LONG-TERM EFFECTS OF SITE IMPROVEMENT AND EARLY WEED CONTROL ON YELLOW-POPLAR PLANTATIONS

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Abstract.--Yellow-poplar (*Liriodendron tulipifera* L.) plantations were established on a bottomland old-field site in 1965 to investigate the effects of site improvement and early weed control on survival and growth. Preplanting treatments included disking alone or preceded by intensive site improvement (green manuring + fertilization). Weed control treatments included 1) a check, 2) chemical (Amizine), and 3) mechanical (cultivation) in each of the first three growing seasons.

Fifteen years after planting, stem diameter at breast height (DBH) and total height were significantly increased by site improvement and weed control treatments, with increases ranging from 10 to 25% greater than the control. Stand survival was markedly increased by weed control but adversely affected by site improvement principally because of increased weed competition. Dry weight yields, on an area basis, were not significantly increased by site improvement, primarily due to lower survival rates in those plots. In contrast, chemical and mechanical weed control increased dry weight yields by 105% and 72%, respectively, over stands receiving no weed control. Treatment effects measured by height, diameter, and survival rate were less apparent than those measured by dry weight yield per hectare. A volume index, using basal diameter squared times height (B^2H) and corrected for mortality, was better correlated with actual yields (r^2=.96), and therefore treatment effects, than either DBH (r^2=.89) or height (r^2=.55) alone.

The volume index growth data indicated that among all treatments, 15-year stand growth steadily increased at the 3 x 3 m spacing used. At current growth rates, the Amizine-treated plots were more than four years ahead of the control plots, while the cultivated plots were about three years ahead.

Keywords: Growth, *Liriodendron tulipifera* L., site improvement, volume index, weed control, yield.

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INTRODUCTION

Yellow-poplar (*Liriodendron tulipifera* L.) is well-suited to plantation culture; it has good form, freedom from major disease and insect problems, valuable wood, and excellent growth potential. Because it approaches its maximum growth potential on a narrow range of soil and site conditions (Doolittle 1958), attention must be given to site selection and/or modification.

Height growth of plantation yellow-poplar has been related to soil characteristics, particularly drainage and surface horizon depth (Merz and Finn 1955, Gilmore et al. 1968, Minckler 1941, Tryon et al. 1960). Unacceptable survival and growth reported for yellow-poplar planted in old-field soils which have poor structure and an eroded surface horizon have confirmed this relationship (Clark and Losche 1969, Francis 1979, Loftus 1974). Another factor in the success of yellow-poplar plantations is soil fertility, particularly nitrogen, and fertilization has often resulted in substantial growth increases (Finn and White 1966, Ike 1962, Buckner and Maki 1977, Gilmore and Boggess 1963, Auchmoody and Smith 1977). High levels of available soil nitrogen can offset otherwise poor soil conditions (Carmean et al. 1976).

One of the problems associated with establishing hardwood plantations on old-fields is controlling the competing vegetation (Shipman 1975). Fitzgerald and Selden (1975) controlled herbaceous weeds chemically with preemergence herbicides (atrazine or simazine) in a yellow-poplar plantation in Georgia. A single, first-season application of both chemicals significantly improved first year height and diameter growth, but only the atrazine treatment resulted in larger seedlings three years after planting. Erdmann (1967) reported similar first-year responses in height and diameter growth of planted yellow-poplar in Iowa to the application of either atrazine or simazine. The complementary effect of weed control and fertilization was shown by Russell (1977) in Tennessee. Either weed control or fertilization alone resulted in nearly the same second year yellow-poplar height growth, but height growth was greatest when weed control and fertilization treatments were combined. Finn and White (1966) cited severe weed competition in fertilized yellow-poplar plantations as the reason for the poor growth of those trees.

This study was initiated in 1964 to investigate the effects of site improvement and post planting weed control treatments on hardwood plantation establishment and development on old-field sites in Indiana (Byrnes et al. 1978). Early effects of weed control on growth and survival have been reported (Byrnes and Murray 1968). Additional information on the effects of weed control and site improvement on survival, growth, and size class distribution has also been reported (Byrnes et al. 1978).

The objective of this study was to investigate the long-term effects of these treatments on the yellow-poplar plantations established as part of the above study. In addition to mensurational data, above-ground dry matter yield and distribution were determined for more complete evidence of treatment effects on growth.

MATERIALS AND METHODS

Study Site

Plantations of yellow-poplar were established on a bottomland, old-field site in west central Indiana in April 1965. The soil is a Genesee sandy loam (mixed, mesic, non-acid Typic Udifluvent) developed in alluvium washed from upland areas of Wisconsin glacial till.

The study was designed to evaluate the growth response of planted yellow-poplar to site improvement and early weed control. The field layout was a randomized block, split-plot design with two replicates of each treatment.

In the year prior to planting, one of the two main plots in each replication received the following site improvement treatments:

1. June 1964 - seed to Sudan grass (*Sorghum vulgare sudanensis*) at 14kg/ha and fertilize with 12-12-12 at 448 kg/ha.

2. September 1964 - plow down Sudan grass, seed to rye grass (*Secale cereale* L.) at 14 kg/ha, and fertilize as in June.

3. April 1965 - plow rye grass down and fertilize as before.

All main plots were disked in April 1965 and 2-0 yellow-poplar seedlings, uniformly graded to a 1.2 m height, were planted at a 3 x 3 m spacing in three .029 ha subplots of 32 seedlings. The 12 seedlings in the center of each subplot provided all subsequent data.

One of three weed control treatments was randomly assigned to each of the three subplots. These included 1) chemical weed control, consisting of a single application of Amizine[1/] at 8 kg/ha over the entire plot in the spring of each of three years following planting, 2) mechanical weed control, consisting of rototilling to a depth of 8 cm three times in each of the three growing seasons following planting, and 3) a check on which no weed control was practiced.

Field Sampling

In early March 1980, 15 growing seasons after planting, trees were measured for total height and diameter at breast height (DBH). In late May 1980, three trees were randomly selected from each plot center for intensive sampling. Each of these was cut 10 cm above ground level and felled onto a tarp, where total height, height to live crown, DBH, and basal diameter (BD) were measured. The tree was separated into foliage, dead branches, live branches, and bole to a 5 cm top and the fresh weight of each component was determined immediately in the field. All tree components were subsampled for dry weight analyses in the laboratory. Live branches were divided into two

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[1/] Trade name for mixture of amitrol (3-amino-s-triazol) and simazine (2-chloro-4,6-bis(ethylamino)-s-triazine) in a 1:3 ratio. Mention of trade names does not constitute endorsement of the products by Purdue University.

size classes based on the branch diameter of the basal end 5 cm from the junction with the main stem. Three branches from each size class, >2.0 cm and <2.0 cm, were subsampled by cutting a 10 cm section from the base, midpoint, and apex. The bole top was considered part of the >2.0 cm branch class. The bole was subsampled by removing a 5-10 cm thick disk from the base and at points 1.5 m along the bole.

All subsamples were placed in plastic bags and kept in coolers until the end of each day, when they were removed to a cold room for storage at 1 °C. The fresh and dry weights of all samples were determined within two weeks of sampling. Bark was removed from bole sample disks prior to drying.

Methods of Analysis

Bole dry weights were determined indirectly using Smalian's volume equation[2/] and disk densities for each 1.5 m bolt. The two disks taken from the ends of each bolt were dried and the density of each disk (dry weight/dry volume) was determined. The values for the disk diameters were used in Smalian's equation and the resulting volume was multiplied by the average density of the two disks for the bolt weight. The bolt weights were summed for bole weight.

To examine the accuracy of this method, green densities (green weight/green volume) for the disks were substituted for dry densities to determine bole green weights by the same method as for bole dry weights. These bole green weights were compared to the actual bole green weights determined in the field. The related regression analyses produced a coefficient of determination (r^2) of .987 and almost all of the predicted green weights were within 5% of actual green weights. Consequently, using this method to determine bole dry weights should be reasonably accurate.

All other tree component dry weights were determined using dry weight/green weight ratios. Stand dry weights were determined using a double sampling approach (Freese 1962). Tree component and total tree dry weight regression equations were developed from the harvested stems, using DBH and total height as the independent variables. These equations were then applied to the core plot inventory data, taken prior to the growing season, to predict tree dry weight yields and distribution. All data was subjected to analysis of variance and, where appropriate, means were separated using the Student-Newman-Keuls test at the 5% level (Snedecor and Cochran 1967).

RESULTS

Stand Characteristics

The March 1980 inventory (Table 1) indicated that site improvement significantly increased total height and DBH. Trees on the site improved plots averaged 11.6 m in height and 13.3 cm in DBH, both significantly greater than 10.5 m total height and 11.9 cm DBH averages on the unimproved plots.

2/ $\text{Volume} = (\text{length})\left(\frac{\text{bottom disk area} + \text{top disk area}}{2}\right)$

Table 1.--Effects of site improvement and early weed control on DBH, total height, survival, and live crown ratio in 15-year-old yellow-poplar plantations.

Treatment	DBH (cm)	Tot.Ht. (m)	Survival (%)	Live Crown Ratio+
Site Improvement:				
None	11.9[b*]	10.5[b]	96[a]	.53[a]
Improved	13.3[a]	11.6[a]	83[a]	.55[a]
Weed Control:				
Amizine	13.3[a]	12.0[a]	98[a]	.46[a]
Cultivate	12.7[ab]	11.1[b]	96[a]	.55[b]
Check	11.5[b]	9.6[c]	75[a]	.61[b]

+Determined on subsampled (cut) trees only.

*Values within a column followed by different letters are significantly different at the .05 level based on the Student-Newman-Keuls test.

The effects of early weed control on tree height growth 13 years after weed control was terminated. Trees in the Amizine weed control treatment averaged 12.0 m and were significantly taller than trees in the mechanical weed control treatment, which averaged 11.1 m. Both weed control treatments significantly increased total height over the control group, which averaged 9.6 m. Weed control had a similar effect on diameter growth. Trees in the Amizine-treated plots averaged 13.3 cm DBH and were significantly greater than the check plot tree average of 11.5 cm. The average DBH for trees receiving mechanical weed control was 12.7 cm and was not significantly different from the other two treatments.

Site improvement appeared to have adversely affected survival. However, this difference was not statistically significant. Weed control improved survival from 75% for the check plots to 96% and 98% for the mechanical and chemical weed control treatments, respectively, but these differences were not significant.

Live crown ratio was determined for all sample trees felled in June (Table 1). In these stands, where age and spacing are the same, lower live crown ratios indicate more advanced stand development and a more fully occupied site. The live crown ratio for the site improvement plots (.55) and the unimproved plots (.53) were not significantly different in these stands. Plots which received the Amizine weed control treatment had a significantly

lower live crown ratio (.46) than those receiving mechanical weed control (.55) or no weed control (.61).

Total tree height and basal diameter in the stands were determined periodically from the time of establishment, so comparisons of these data can be made between treatments as the stands developed. The beneficial effect of site improvement on tree height and diameter growth was delayed until six years after plantation establishment (Figure 1). At that time the total height of trees in the site improvement plots significantly exceeded that of trees in the unimproved plots. This difference has remained statistically significant through age 15 years. Significant differences in basal diameter coincided with increased height growth, but, unlike height growth, the difference in the rate of diameter growth continued to increase.

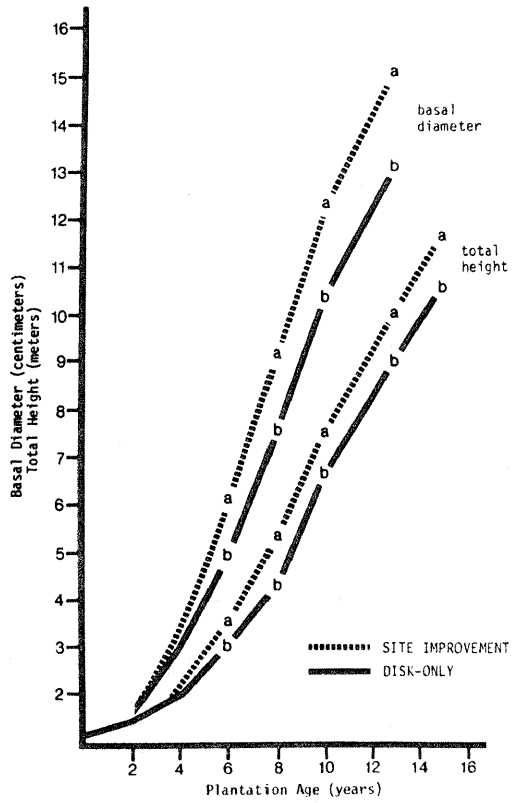

Figure 1.--Effects of site improvement on plantation yellow-poplar total height and basal diameter. Different letters in one year indicate significant differences at the .05 level based on the Student-Newman-Keuls test.

The response to weed control in total height and basal diameter growth was established early in these stands and continued through age 15 (Figure 2). Three years after planting, total tree height was significantly different for

all three treatments (Amizine > cultivation > check). Increases in basal diameter due to weed control generally followed the pattern expressed by total height, except that after the eight year sampling date the Amizine treatment was no longer significantly greater than the cultivation treatment (Figure 2).

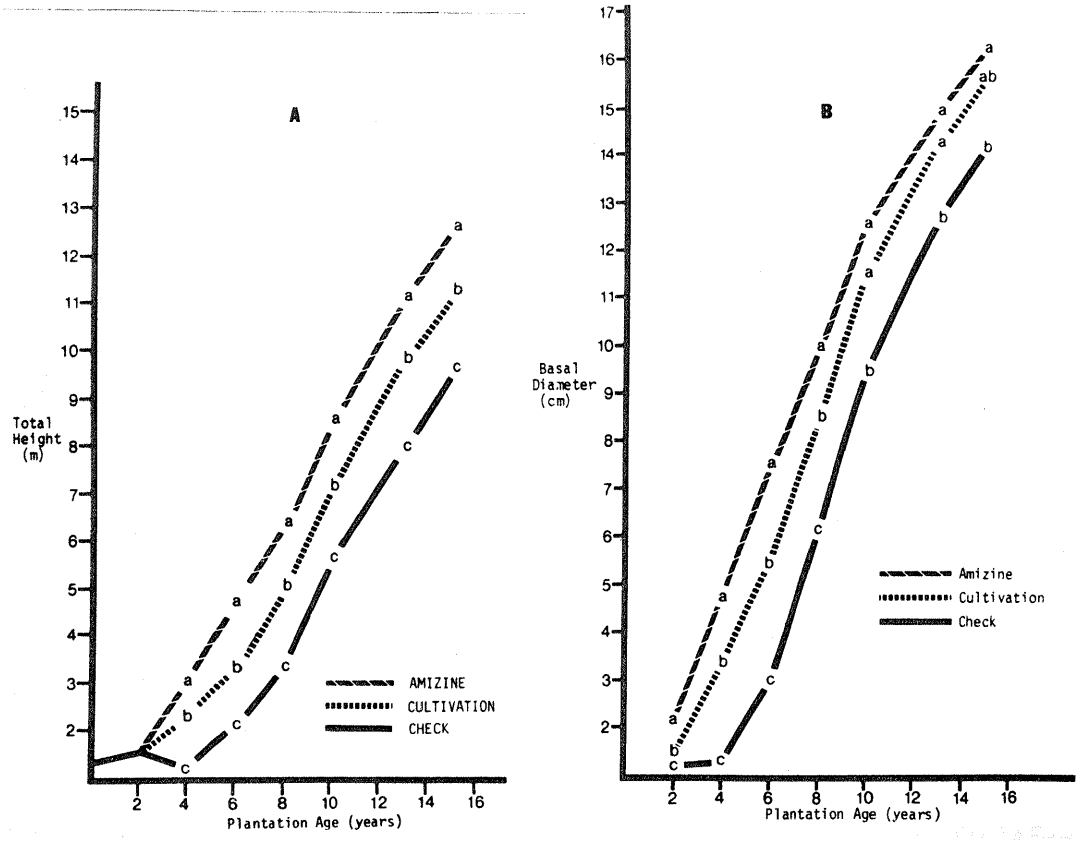

Figure 2.--Effects of weed control on plantation yellow-poplar: A. total height. B. basal diameter. Different letters in one year indicate significant differences at the .05 level based on the Student-Newman-Keuls test.

Above-ground Dry Weight

Regression equations were developed from the trees harvested in June 1980 to predict dry weight yields for various tree components from DBH and total height. These equations were then applied to the inventory data taken the previous winter to compare treatment effects on dry weight yields. Nomenclature in this section follows that of Saucier (1979).

Complete tree above ground (CT_{ag}) yields were 44,000 kg/ha for improved plots and 38,000 kg/ha for unimproved plots, a difference which was not significant (Figure 3). Lower survival rates in the improved plots, particularly where weed control was not practiced, essentially eliminated

potential dry weight yield increases due to site improvement when expressed on an area basis.

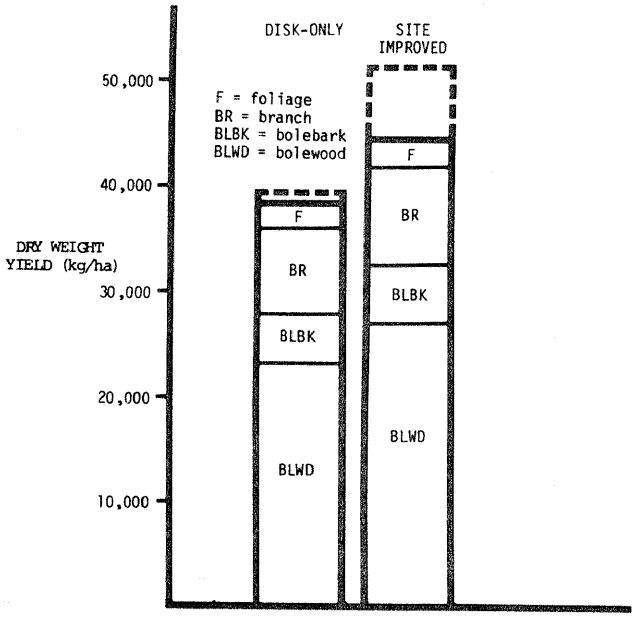

Figure 3.--Effects of site improvement on above-ground dry weight yields and distribution in 15-year-old yellow-poplar plantations. Dashed lines indicate yields assuming 100% survival.

Survival had the opposite effect on plot yields with weed control. Yields for plots receiving Amizine and cultivation were not significantly different until survival rates were included. The Amizine treated plots yielded 51,000 kg/ha compared to 43,000 kg/ha in the plots receiving cultivation. In either case the check plots yielded significantly less CT_{ag} dry weight, with actual yields of 25,000 kg/ha which was approximately one-half of the yields of the Amizine treated plot.

When the yields of above-ground dry matter are divided into the various tree components, the pattern of treatment effects follows very closely that of the above CT_{ag} yields (Table 2 and Figures 3-4).

Regression equations to predict the effect of various treatments on dry weight yields were used in this study and in many others. Another, more indirect method of determining treatment effects would be to use a combination

Table 2.--Effects of site improvement and early weed control on the survival and above-ground dry weight distribution in 15-year-old yellow-poplar plantations. Values are based on regression equations determined from harvested stems.

Treatment	% Surv.	Foliage kg/ha	Foliage %	Branch kg/ha	Branch %	Bolewood kg/ha	Bolewood %	Bolebark kg/ha	Bolebark %	Total kg/ha
No Site Improvement	96	1908	5.0	8168	21.5	23062	60.7	4863	12.8	38001
Site Improvement	83	1942	4.4	9373	21.4	27050	61.8	5438	12.4	43803
Amizine	98	2100	4.1	10730	21.1	31656	62.3	6327	12.5	50813
Cultivate	96	2056	4.8	9145	21.4	26176	61.2	5387	12.6	42764
Check	75	1525	6.1	5556	22.4	14510	58.4	3240	13.1	24831
Average	90	1924	5.2	8720	21.8	24917	59.8	5130	13.2	40688

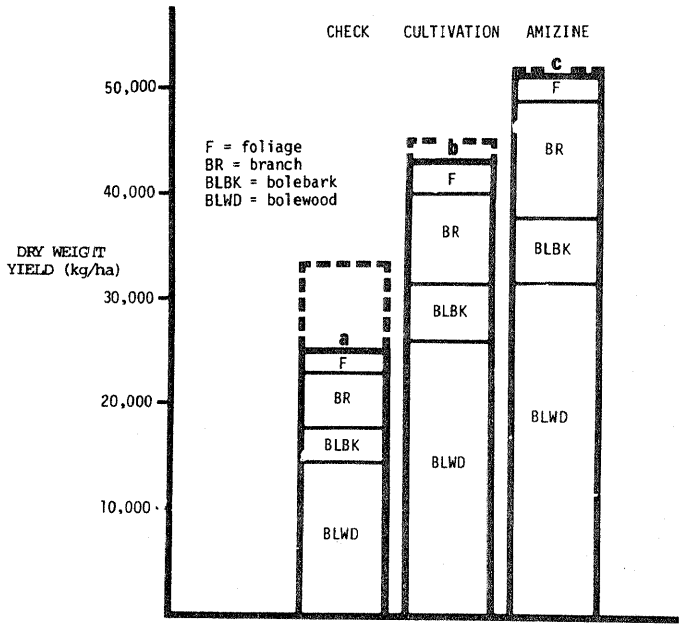

Figure 4.--Effects of early weed control on above-ground dry weight yields and distribution in 15-year-old yellow-poplar plantations. Dashed lines indicate yields assuming 100% survival. Different letters indicate significant differences at the .05 level based on the Student-Newman-Keuls test.

of diameter and height measurements. The total above ground dry weight yields at age 15 correlated with both $(DBH)^2H$ and $(Basal\ Diameter)^2H$, with r^2 values of 0.947 and 0.962, respectively. Such a "volume index," when calculated for a given size distribution and survival rate, therefore accurately predicted actual differences in yields between treatments.

Of particular interest is a comparison of treatment effects between the diameter and total height measurements and the volume index and total dry weight measurements. By 1979, the Amizine treatments had resulted in a 16% increase in DBH and a 25% increase in total height over the check treatment. However, the increase in volume index and total dry weight were 117% and 105%, respectively. In Figure 5 the volume index values for the three weed control treatments are plotted against stand age. By comparing this figure to Figure 2, it is evident that volume index (as with dry weight) is more sensitive to treatment differences than either diameter or total height measurements alone.

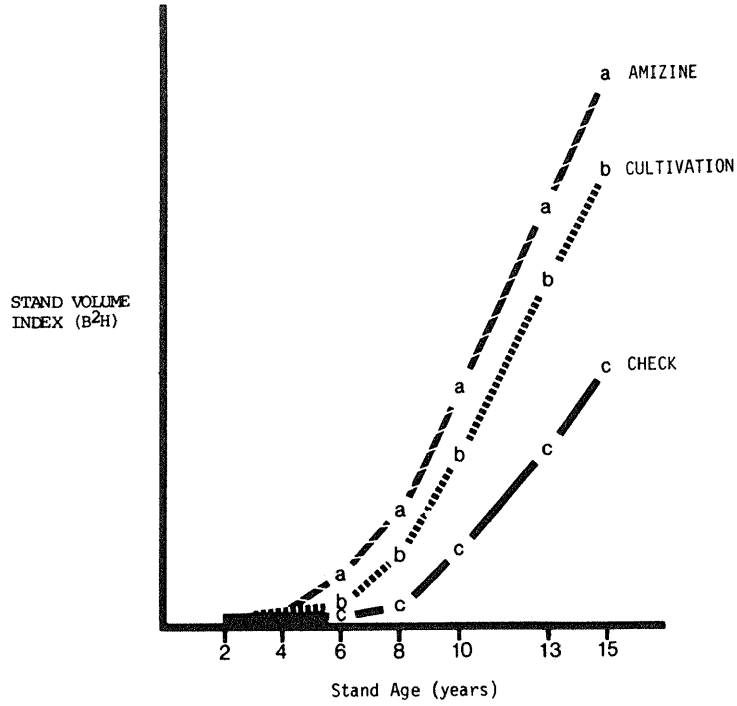

Figure 5.--Effects of weed control on total stand volume index (B^2H) of yellow-poplar plantations. Numbers for volume index are meaningless and so are not given on B^2H axis. Different letters at a given age indicate significant differences at the .05 level based on the Student-Newman-Keuls test.

DISCUSSION

The growth response to weed control and site improvement treatments can be measured in a number of different ways, such as total height, diameter, a combination of both, or dry weight. In this study, volume index and stand dry weight were more responsive to treatment differences than total height and diameter.

The decline in annual height and basal diameter increments indicates that these stands are beginning to fully occupy the site. However, the steady increase in volume growth (Figure 5) suggests that the stands are in a rapid growth phase. Growth expressed as volume index is probably a better indication of actual stand growth rates than either total height or diameter. This hypothesis assumes that volume index correlates as well with dry weight at earlier stages of growth as it did at the time of harvest. Using volume index as an indicator, the stands do not appear to have fully occupied the site at this spacing (3 x 3 m) 15 years after planting.

The positive response of yellow-poplar to site improvement was delayed until six years after planting, after which all growth parameters were greater in the site improvement plots. The reason for the delay in response may be that the relatively high C/N ratio of the green manure crop residue resulted in immobilization of the added soil N (Allison 1966). Once the C/N ratio was lowered through decomposition, N mineralization became possible, making the added N available to the trees.

Yellow-poplar height growth in this study is compared with that in 13 published studies on plantation yellow-poplar in Figure 6. The "best" and "worst" height growth for individual treatments from the studies cited (Table 3), where applicable, are plotted along with the total height growth curves for the "best" and "worst" weed control treatments in this study. The Amizine weed control treatment resulted in substantially less growth than the maximum for all plantations surveyed, but only slightly less than the maximum growth in other plantations in this region. The check plots grew more slowly than most of the plantations in other studies, but were generally ahead of the poorest plantation growth in the region.

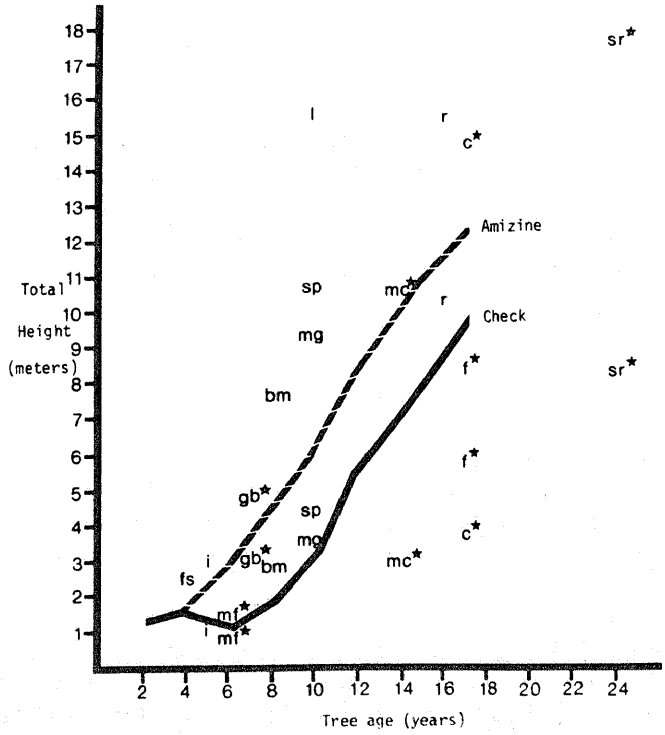

Figure 6.--A comparison of plantation yellow-poplar height growth in the present study with that of previous studies. Letter symbols represent published total height values listed in Table 3. Starred symbols represent studies done in the Central Hardwoods Region.

Table 3.--Total height growth of plantation yellow-poplar in previous studies.

Reference	Location	Site Type	Age	Total Height (m) Best*	Total Height (m) Worst	Graph Symbol
Gilmore & Boggess (1963)	So. Ill.	agric. field	7	4.9	3.0	gb
Fitzgerald & Selden (1975)	Ga.	forest	4	2.5	1.7	fs
Schomacher & Rudolph (1964)	Mich.	old field	24?	17.7	8.2	sr
Russell (1977)	Tenn.	forest	16	15.5	10.4	r
Ike (1962)	Ga.	old field?	5	3.0	1.2	i
Buckner & Maki (1977)	Tenn.	forest	8	7.6	2.9	bm
Merz & Finn (1955)	Ohio	old field	6	1.3	0.8	mf
Carmean et al. (1976)	Ind.	forest/old field	17	14.9	3.7	c
Loftus (1974)	Tenn.	old field	10	15.6	-	l
Smalley & Pierce (1972)	Tenn.	old field	10	10.7	4.3	sp
McGee (1977)	Tenn.	forest	10	9.4	3.7	mg
Funk et al. (1974)	Ohio	old field	17	8.2	5.8	f
McCarthy (1933)	Ohio	old field	14	10.7	3.0	mc

*Best is the greatest mean total height cited for all treatments; worst is the lowest mean total height cited for all treatments.

In this study, weed control resulted in growth responses early in stand development. By the end of the second year, the Amizine treatment resulted in a significant increase in growth, and the growth response to all three weed control treatments were significantly different after year four. Amizine was superior to cultivation apparently because the chemical treatment was more effective in controlling the competing vegetation.

Moisture appeared to be the limiting factor in the early stages of growth (Byrnes and Murray 1968). This is probably why the lower survival rate occurred in the site improvement plots. The increased fertility of the improved plots stimulated weed populations, which competed with the seedlings for moisture in the early stages of seedling establishment. In fact, only 67% of the seedlings survived on improved plots receiving no weed control, compared to 88% on unimproved plots receiving no weed control.

There were large differences in dry weight yields among weed control treatments in comparison to differences in height and basal diameter measurements. While a number of studies have shown the improvement of growth in yellow-poplar plantations due to weed control (Fitzgerald and Selden 1975, Russell 1977, Erdmann 1967), the magnitude of the volume or dry weight growth improvement has not been quantified. In this study, the volume and dry weight of the Amizine-treated plots are more than 100% greater than those of the control stands, far exceeding the differences in height (25%) and diameter (16%). Differences in volume index, and presumably dry weight, were even greater at earlier stages of stand development.

The variables DBH and $(DBH)^2H$ were found to be of equal value in estimating either total tree or stem dry weight of Virginia pine (Pinus virginiana Mill.) (Madgwick 1971) and jack pine (Pinus banksiana Lamb.) (Crow 1971) stands. Others have found $(DBH)^2H$ to be superior to DBH alone as an estimator of stem (tree) dry weight (Zavitkovski 1971, Peterson et al. 1970, Schreuder and Swank 1971, Johnstone 1971). Both Madgwick (1971) and Crow (1971) point out that when dealing with stands having widely distributed size classes or when comparing dry weights across many stands, $(DBH)^2H$ is superior to DBH alone. In this study, basal diameter squared times height (B^2H) was slightly superior to $(DBH)^2H$ (r^2 = .96 vs. r^2 = .94) and was therefore used for dry weight predictions and comparisons.

Stand volume and dry weight yields were more responsive to treatment differences than diameter and height measurements because volume is a function of squared diameter times height. Differences in diameter and height are magnified exponentially when translated into stand volume. In addition, stand volume and dry weight yields can (and should) include actual survival rates, while height and diameter measurements cannot. In this case, survival rates were a significant factor in the calculation of treatment effects. Site improvement significantly increased height and diameter, but lower survival rates in those plots reduced actual plot dry weight yields to a level not significantly different from the unimproved plots. Survival rates had the opposite effect among weed control treatments and actually increased differences in plot dry weight yields between the treatments.

The volume index curves indicate that the plots treated with Amizine were more than four years ahead of the check plots, and the cultivated plots were about three years ahead. Essentially, weed control released the trees until

they could compete with the herbaceous vegetation, and allowed the trees to enter their fastest (logarithmic) growth phase earlier than the trees receiving no weed control. A similar effect of planting large (>38 cm) versus small (25-38 cm) yellow-poplar seedlings was also found to be significant, with the large seedlings three years ahead of the small seedlings in height growth at age 16 (Funk et al. 1974). In this study the volume growth rate appears to be constant in stands which received weed control, but is increasing in the control plots.

SUMMARY AND CONCLUSIONS

The effects of preplanting site improvement and early weed control in a yellow-poplar plantation remained evident 15 years after planting. Site improvement significantly increased total height and diameter, but lower survival rates due to increased weed competition in that treatment reduced stand dry weight yields to near the dry weight yields of the unimproved plots.

The positive response to weed control was established early and has not changed significantly after 15 years. Plot dry weight yields were significantly improved with both weed control treatments, but the Amizine treatment was superior to the cultivation treatment, apparently due to more complete weed control. Total above-ground dry-weight yields ranged from 51,000 kg/ha for the Amizine-treated plots to 25,000 kg/ha for the weed control check plots. With increasing size class, stems in these plantations tended to have more of the total above-ground dry weight in bolewood and less in bolebark, branch, and foliage components. An index of volume, (basal diameter)^2 x (height), was highly correlated with dry weight, and accurately reflected stand dry weight yield differences among treatments when calculated using actual survival rates.

The tree heights attained in the plots which received Amizine weed control are nearly as good as the maximum attained in other yellow-poplar plantations in the Midwest, but fall substantially short of those attainable in the South.

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