The Influence of Herbaceous Weed Control and Seedling Diameter on Six Years of Loblolly Pine Growth—A Classical Growth Analysis Approach

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ABSTRACT. Classical growth analysis equations were applied to three loblolly pine (*Pinus taeda* L.) seedling ideotypes (determined by groundline diameter) that were subjected to either 2 years of complete herbaceous weed control (low weed abundance: *LWA*) or no herbaceous weed control (high weed abundance: *HWA*). For the first 2 growing seasons, seedlings of the *LWA* treatment had greater mean relative growth rate ($\overline{RGR}$) and mean net assimilation rate ($\overline{NAR}$) values. However, during years four through five, $\overline{RGR}$ and $\overline{NAR}$ were significantly lower in the *LWA* treatment than in the *HWA* treatment. The reduction in herbaceous weed interference appeared to reduce mean leaf area ratio ($\overline{LAR}$) throughout the study period.

Several trends in this data set suggest that growth analysis parameters may be confounded with size. The largest ideotype generally exhibited the smallest $\overline{RGR}$, and $\overline{RGR}$ declined as trees increased in biomass. To remove the potential confounding of size, the basis of comparison was changed from trees of equal age to trees of equal biomass (total aboveground dry weight at the beginning of each growing season). This method resulted in a different interpretation of the results. For a given biomass, trees in the *LWA* treatment had greater $\overline{RGR}$ and $\overline{LAR}$ than those in the *HWA* treatment throughout the study period. Growth of seedling ideotypes within a given weed abundance treatment all fell along a single curve, suggesting that there was no apparent interaction between initial seedling diameter and herbaceous weed control.

After the trees reached six kg biomass, the direct benefits from reduced herbaceous interference had apparently ceased. Initially, large differences in $\overline{NAR}$ were observed between treatments, but these differences diminished as trees approached 5 kg. In contrast, differences in $\overline{LAR}$ were initially small but increased as tree biomass increased. As trees increased in biomass, the partitioning of carbon into leaf area seems to be more responsible for the productivity gains associated with weed control. FOR. SCI. 37(2): 655–668.

ADDITIONAL KEY WORDS. Seedling quality, relative growth rate, net assimilation rate, leaf area ratio, competition.

H ISTORICALLY, PRACTICING FORESTERS in the southern United States have not considered herbaceous weed competition an important factor constraining pine growth or survival (Gjerstad and Barber 1987). However, a number of studies in the last decade have reported increased pine growth

resulting from reductions in herbaceous weed interference (Creighton et al. 1987, Dickson et al. 1989, Glover et al. 1989). Because of these large growth responses, interest in operational use of this practice has increased dramatically. Huang and Teeter (1990) reported that the use of herbaceous weed control by the forest industry during the last decade has increased sixteen-fold.

Walstad and Kuch (1987) suggest that sound vegetation management requires an understanding of how weed control interacts with other silvicultural practices so that optimum efficiency can be integrated in a management system. Although the interaction of weed control and fertilization has been studied (Swindel et al. 1988, Tairks and Haywood 1986), few interactions between weed control and other silvicultural practices have been investigated. Fry and Poole (1980) suggest that improved growth due to outplanting larger diameter seedlings will potentially result in interactions among the tree, the site, and the weed competition. However, information regarding these interactions is limited. Mitchell et al. (1988) reported that no interactions were present between weed control and initial seedling diameter for third-year height and diameter of loblolly pine (*Pinus taeda* L.); yet a significant interaction was present for volume growth.

The absolute growth of a tree may not be a reliable measure of its performance, particularly when the populations of interest differ in size. Tree growth is influenced by tree size (Perry 1985). Removing the confounding of size is especially important when comparing the growth of trees with large treatment-induced differences (Auchmoody 1985). Differences in tree size can result either at time of establishment (if different stock types are planted) or after the stand has responded to some silvicultural practice, such as planting at different densities (Brand et al. 1987), fertilization (Comerford et al. 1980, Auchmoody 1982), and/or thinning (Hall et al. 1980).

Determining the direct effect of a silvicultural practice that results in large growth responses can be overestimated if trees are not evaluated at comparable initial sizes. Auchmoody (1985) reported the confounding of growth due to size inequality between fertilized and unfertilized trees had to be taken into account if the direct fertilizer response was to be properly evaluated. Failure to recognize the indirect effects produced inflated estimates of the duration of fertilization response. Removing the confounding of size can be done in several manners. One approach involves the use of regression models to partition out direct effects (the growth response that can be attributed directly to the continuing effect of the treatment) and an indirect effect (growth due to size differences previously induced by the treatment) (Auchmoody 1985, Wagner 1990). A second means of evaluating the growth of two or more populations that may differ in size is by the use of classical growth analysis (Hunt 1982). The equations used in classical growth analysis are frequently used to remove the confounding of size. Also, these techniques provide insight into the changes in plant function (such as alterations in carbon partitioning, and/or increased growth per unit area of foliage) which determine the magnitude of the response (Radosevich and Osteryoung 1987). Few published data are available that illustrate the alteration in tree function that may account for the growth responses due to weed control. Furthermore, no data are published which can be used to determine the duration of weed control responses for southern pines when the confounding of tree size is removed.

The objectives of this study were to: (1) determine the value of classical growth analysis in evaluating duration of growth increases for loblolly pine due to weed control and seedling ideotypes; (2) determine the plant responses that are the most important factors contributing to the growth responses arising from weed control; and (3) determine whether an interaction between seedling diameter (a consistent predictor of growth upon outplanting) and weed control exists during the first 6 years of stand development.

MATERIALS AND METHODS

STUDY AREA

The study area was located in the Upper Coastal Plain of Alabama. Soils were classified in the Marvyn series (Typic Hapludalts). Prior to the study, the site was occupied by a mature stand of loblolly and longleaf (*Pinus palustris* Mill.) pines. A salvage cut was conducted in 1975 after a hurricane damaged the stand, and residual trees were harvested late in 1980. During the winter of 1980–81, the site was prepared for planting using a single roller-drum chopper.

During the first 2 weeks of July, 1982, the site was treated with a tank mix containing 0.6 kg ae/ha of picloram plus 4.5 kg ae/ha of 2,4-D (7.6 liters Tordon 101) plus 4.5 kg ae/ha triclopyr ester (Garlon 4). Herbicides were diluted with sufficient water to apply 125 l/ha using a CO_2 pressured backpack sprayer. Eight weeks after herbicide application, the area was broadcast burned. In January 1983, the site was hand-planted at a 2.4 × 2.4 m spacing, with 1-0 bareroot, genetically improved loblolly pine seedlings from the Hammermill Paper Company Nursery near Selma, AL.

EXPERIMENTAL DESIGN

The study was established using a randomized complete block design with four blocks. Blocks were located by topographic position and depth of surface soil. Plots maintained specifically for tree biomass sampling were also established in a manner consistent with the study design. Centered in each 0.1-ha treatment plot was a measurement plot of 9 rows of 9 trees. Herbicides were used to establish two distinct levels of herbaceous weed interference beginning in April of the first growing season. High weed abundance (*HWA*) plots had no herbaceous weed control through the duration of the study. Low weed abundance (*LWA*) plots had 2 years of complete weed control. At the time of weed emergence, sulfometuron was applied at the rate of 0.42 kg ai/ha the first growing season and 0.26 kg ai/ha the second growing season. After each application of sulfometuron, new weed growth was controlled by directed sprays of glyphosate (2% v:v in water). In all plots, nonpine woody vegetation was controlled with cut stump applications of triclopyr as described by Zutter et al. (1986). Seedling groundline diameter was measured immediately after outplanting. Seedlings were grouped into three ideotypes as defined by Mexal and South (1991). The ideotypes were seedling types A (>4.0 mm); B (3.0–4.0 mm); and C (<3.0 mm).

SAMPLING PROCEDURE

Herbaceous weeds were assessed each of the first 6 growing seasons during the latter 2 weeks of September or the first week in October. Six 1.0-m^2 quadrats were randomly located within each plot, and a visual estimate was made to the nearest 5% of ground covered by herbaceous weeds. At the end of the second through the sixth growing seasons, cover was also estimated for individual species or species groups. After cover assessment, herbaceous weeds were clipped at groundline, bagged, and dried to a constant weight at 70°C (Zutter et al. 1987).

Trees were destructively sampled during the first, second, third, and fifth years after outplanting from the previously mentioned biomass plots and the sixth year from the inner border rows of the measurement plots. Trees were removed over time from the biomass plots so as not to induce a thinning effect on sample trees taken in later years. Trees were stratified into three size classes by either diameter at groundline (Zutter et al. 1986) or breast height depending on tree size at the time of sampling. Sample trees were randomly selected from each size class to ensure the range of tree sizes was well represented. From each combination of treatment and replicate, 25 to 30 trees were sampled at the end of the first and second growing seasons, 15 trees were sampled the third growing season, and 12 each the fifth and sixth growing seasons. For each sampling period, trees were partitioned into foliage, stem, and branch components. All trees less than 5 years old were brought into the laboratory for dry weight determination. Five- and six-year-old trees were sampled in the field by recording fresh weight of each component to the nearest 2 g by whorl. If samples were larger than 100 g, subsamples of a representative branch, approximately 100 g of foliage, and a 5 cm length from the bottom portion of each stem section were taken from each whorl for dry weight determination. Component samples less than 100 g were sealed in plastic bags and refrigerated until fresh weight could be determined in the laboratory. Component dry weights for the entire tree were calculated by multiplying the fresh weight of the respective component by its dry/fresh weight ratio for a given whorl, and summing the values for each whorl for individual trees.

LEAF AREA

Ten seedlings were selected from both 1- and 2-year-old seedlings from the *LWA* and *HWA* regimes for quantification of fascicle morphology and leaf area. After seedlings were cut in the field, fascicles were moistened and trees placed into plastic bags and stored at 2°C until they were processed (Zutter et al. 1986).

For each 1-year-old seedling, leaf area was determined for 4 subsamples of 10 fascicles. Sampling was restricted to current (present year) three-needled fascicles as preliminary sampling indicated older (previous year) three-needled fascicles and current four-needled fascicles each averaged less than 5% of total foliage weight. Fascicles of 2-year-old seedlings were stratified by upper and lower crown position and fascicle type (number of needles per fascicle). Sampling again was restricted to current foliage. For each crown position, approximately 100 fascicles were selected from throughout the position.

Use of Johnson's method for assessing leaf area allowed calculation of mean fascicle length, mean weight, surface area, diameter, specific leaf area, and den-

sity (Johnson 1984). Fascicle sheath lengths were also observed, allowing calculation of mean sheath length and the proportion of the fascicle covered by the sheath. For these fascicle attributes, a mean was calculated for each combination of crown position and fascicle type for two-year-old seedlings. Mean values for the entire tree were calculated by weighing the means for combinations of crown position and fascicle type by their respective proportion of total foliage weight. Mean values for 1-year-old seedlings were calculated by averaging the four three-needled fascicle subsamples. Total needle surface area for each tree was determined by multiplying the mean specific leaf area by total foliage dry weight (Zutter et al. 1986).

The remaining leaf area determinations were done in a similar fashion with few modifications. For 3-, 5-, and 6-year-old trees, 20 fascicles per whorl were taken at random, and projected leaf area and dry weight were determined. Projected leaf area was measured, using a Li-Cor Li 3000 portable area meter, on all trees sampled. After the third, fifth, and sixth growing season, six trees per treatment per block were randomly selected for determining the ratio of total leaf area to projected leaf area. Total leaf area was quantified by water displacement using the 20 randomly selected fascicles per whorl (Johnson 1984). There was little variation in the ratio of total/projected leaf area within an individual crown or between trees, therefore a constant of 3.30 was used to convert projected leaf area to total leaf area. Specific leaf area, $cm^2 g^{-1}$, was calculated as reported by Johnson et al. (1985). Foliage biomass per whorl was multiplied by specific leaf area to determine the total leaf area for that whorl. Leaf area per tree was simply the sum of the leaf area per whorl added for all whorls present for a particular tree.

ALLOMETRIC EQUATIONS

Regression equations were developed using a log-log model, with the transformation bias correction factor suggested by Baskerville (1972), to relate D^2H (the square of diameter times height) to total and component biomass in treatment plots. In general, separate equations were developed for each treatment and age combination. Groundline diameter was used at planting and age 1. Diameter at 15 cm (above the groundline) was used at all other ages. Using this approach, r^2 values ranged from 0.87 to 0.98 for total biomass over the 6-year study period. Leaf area could be accounted for with similar precision (Britt et al. 1990). Biomass at time of planting was calculated using the same log-log regression procedure, with D^2H as the independent variable, from a dataset obtained from the Auburn University Southern Forest Nursery Management Cooperative. Data represent leaf area and biomass of seedlings as a function of diameter and height from 12 southern nurseries (Larsen et al. 1986). Total and component biomass were calculated using the equations and individual tree diameter and height measurements.

GROWTH ANALYSIS

Mean relative growth rate ($\overline{RGR}$) and its components, mean net assimilation rate ($\overline{NAR}$) and mean leaf area ratio ($\overline{LAR}$), were calculated for the aboveground portion of the trees sampled using the following equations (Hunt 1982):

$$\overline{RGR} = \frac{\ln w_2 - \ln w_1}{t_2 - t_1} \qquad (1)$$

$$\overline{NAR} = \frac{w_2 - w_1}{t_2 - t_1} \times \frac{\ln LA_2 - \ln LA_1}{LA_2 - LA_1} \qquad (2)$$

$$\overline{LAR} = \frac{(LA_1/w_1) + (LA_2/w_2)}{2} \qquad (3)$$

where

w_2 is the aboveground dry weight at time n.

w_1 is the aboveground dry weight at time $n - 1$.

$t_2 - t_1$ is the time in years from $n - 1$ to n.

LA_2 is the leaf area at time n.

LA_1 is the leaf area at time $n - 1$.

These three parameters were calculated for years one, two, three, and six. Since no biomass sampling was done in year four, $\overline{RGR}$, $\overline{NAR}$, and $\overline{LAR}$ were calculated for years 4–5 using w_1 biomass at the beginning of year 4, w_2 biomass at end of year 5, and $t_2 - t_1 = 2$ years. The use of these equations are in accordance with the recommendations of Radford (1967).

Ideotype and treatment effects on biomass, $\overline{RGR}$, $\overline{NAR}$, and $\overline{LAR}$ were tested using analysis of variance for a split-plot design. All significance tests were made at the $P = 0.05$ level, unless otherwise specified.

RESULTS AND DISCUSSION

The weed control treatments significantly decreased both the percentage cover of herbaceous weeds and the herbaceous weed biomass present (Table 1). During the first 2 years, herbaceous biomass in *HWA* treatment was nearly two orders of magnitude greater than that observed in the *LWA* treatment. During years 3 and 4, herbaceous weeds increased, reaching a maximum of 530 kg ha^{-1} in the *LWA* treatment. Nevertheless, herbaceous biomass in the *HWA* treatment was more than six times greater than in *LWA* plots during years 3 and 4. The dominant herbaceous weed present throughout the study was *Andropogon virginicus* L. During the first 2 years, *Andropogon* was associated with *Conzya canadensis* (L.), *Eupatorium capillifolium* (Lam.) Small and *Panicum* spp. From years three through six, *Andropogon* became even more dominant and *Rubus* spp. (blackberry) became an important component (Britt et al. 1990).

Decreased weed abundance significantly increased aboveground pine biomass for the first 3 years of this study (Zutter et al. 1986, 1987). These differences continued through year 6 and appear to be increasing in absolute magnitude (Table 2). In addition, ideotype affected tree biomass throughout the study period regardless of weed competition. The interactions between weed competition and ideotype during the first 3 years are ones of scale rather than rank. By year 5, the mean difference in dry weight gain between ideotype A seedlings and ideotype

TABLE 1.

Herbaceous weed cover and biomass for two weed abundance treatments for the first 6 years of stand development.

Weed abundance[1]	Growing season after outplanting					
	1	2	3	4	5	6
	.... (cover %)					
High	73 a[2]	82 a	81 a	62 a	63 a	68 a
Low	2 b	1 b	24 b	7 b	4 b	3 b
	.... (Biomass kg ha^{-1})					
High	2695 a	2399 a	3307 a	3439 a	1727 a	1240 a
Low	30 b	15 b	367 b	530 b	72 b	68 b

[1] High weed abundance treatment was obtained by using no herbicides to control herbaceous weeds. The low weed abundance treatment resulted from two years of herbaceous weed control.

[2] Means within a year and followed by a different postscript letter are significantly different ($P < 0.05$) using the Student's t-test.

C seedlings was more than 4 kg per tree for the *LWA* treatment. Using the same comparisons, a difference of less than 2 kg was observed when trees were grown in the presence of weeds. Absolute gains from planting larger diameter seedlings can be enhanced when stress induced by herbaceous weed interference is reduced. However, year 6 data suggest that differences between ideotypes declined during year 6. This may be an artifact of an ice storm in February 1988, which damaged larger trees to a greater extent than smaller trees. In the *LWA* treatment a 5 kg difference in biomass existed between ideotype A and C if only undamaged trees were analyzed (data not shown). It is not clear whether the ideotype A trees will regain the apparent dominance they showed during the first 5 years of stand development. Others have reported that large gains can be realized from planting larger diameter seedlings over study periods ranging

TABLE 2.

Aboveground biomass of loblolly pine trees of three diameter classes growing with low and high herbaceous weed abundance.

Weed abundance[1]	Diameter class	Growing season after outplanting				
		1	2	3	5	6
	(mm)	.... (kg tree^{-1})				
High	>4	0.03 a	0.24 a	1.02 a	6.38 a	10.45 a
	3 to 4	0.02 b	0.17 b	0.78 b	5.34 ab	8.73 ab
	<3	0.01 b	0.13 b	0.63 b	4.53 b	7.63 b
Low	>4	0.13 a	2.25 a	9.53 a	24.48 a	29.10 a
	3 to 4	0.08 b	1.75 b	8.09 ab	20.57 b	26.81 a
	<3	0.06 b	1.44 b	7.17 b	19.76 b	26.76 a

[1] Weed abundance treatments are defined as in Table 1.

[2] Means within a column and weed abundance treatment and followed by the same postscript letter are not significantly different ($P < 0.05$) using Duncans' New Multiple range test.

from 13 to 30 years (Wakeley 1969, Blair and Cech 1974, South et al. 1985, 1988).

Although comparisons such as these are common in the literature, several authors suggest that care must be exercised in comparing responses of trees when treatment-induced growth differences occur early in the study period (Ledig 1974, Radosevich 1984, Zedaker et al. 1987, Dickson et al. 1989). The difficulty in comparing the subsequent growth of different sized plants arises because trees grow as a function of their size (Perry 1985). With other factors held constant, large-diameter seedlings have greater absolute growth rates than smaller ones. Thus, when a particular treatment induces size differences, the absolute growth of trees can be partitioned into two components: (1) growth attributed to the continued effect of the treatment, and (2) the increased growth simply due to the increased size of the individuals (Auchmoody 1985). Thus, determining the duration of the response requires the removal of confounding of size with growth (Wagner 1990). This has traditionally been done by using classical growth analysis techniques described by Hunt (1982) and Evans (1972).

Several trends were detected when growth analysis techniques were applied to this data set. First, $\overline{RGR}$ of trees released from herbaceous weed interference was significantly greater than that observed for the trees growing under the influence of weeds for the first 2 years. By year 3, the $\overline{RGR}$ was approximately the same for trees in each of the weed control treatments; however, after the third year, trees growing in the presence of weeds exhibited larger $\overline{RGR}$ than trees growing in the absence of weeds (Figure 1).

Interpretation of these data must be done with care. If $\overline{RGR}$ removes the confounding of size from the effect of treatment, one would conclude that after the third year, trees from the HWA treatment were actually "gaining ground" on
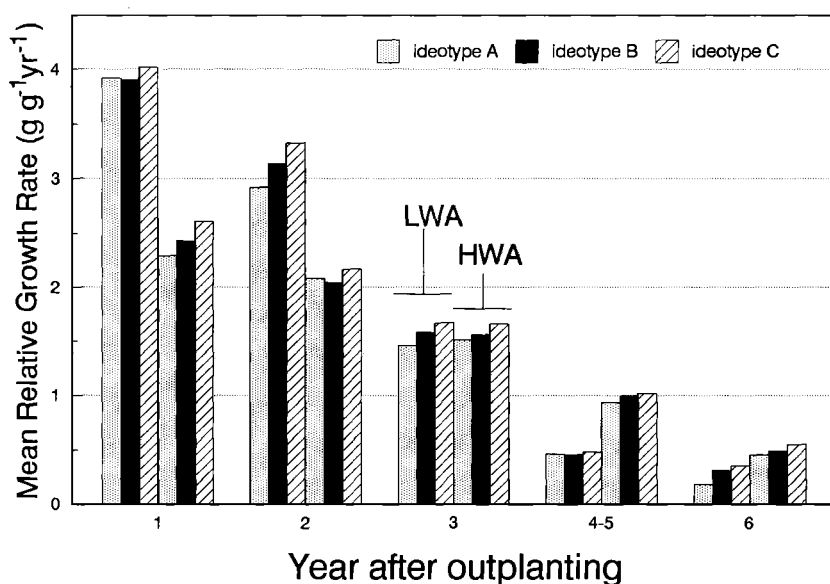

FIGURE 1. Mean relative growth rate for three seedling ideotypes grown with (HWA) and without (LWA) herbaceous weed interference for the first 6 years after outplanting. Ideotypes are defined by Mexal and South (1991) as: A = diameter greater than 4 mm; B = diameter ranges from 4 mm to 3 mm; C = less than 3 mm.

those that were grown under low weed interference. The decrease in $\overline{RGR}$ might be attributable to accelerated competition between the pines themselves. However, if this is the case the trees in the *HWA* plots would be "gaining ground" only if at a similar size their $\overline{RGR}$ was higher than those in the *LWA* treatment. The trees in *LWA* plot that are growing at a greater $\overline{RGR}$ early on are nearly an order of magnitude larger (in aboveground biomass) by year 3. When trees in the *HWA* treatment reach the same biomass as those in the *LWA* treatment, competition among the pines is likely to reduce $\overline{RGR}$ to comparable levels.

A second interpretation is that traditional application of classical growth analysis equations, as done here, does not remove the confounding of size. Indeed, Brand et al. (1987) reported that traditional use of classical growth analysis equations did not remove the confounding of size. They found that when $\overline{RGR}$ and $\overline{NAR}$ were derived from the aboveground growth of red pine (*Pinus resinosa* Ait.) at various spacings over 30 years, the effect of size was not removed. The $\overline{RGR}$ of large trees is usually less than that of smaller trees, a trend also reported by Perry (1985).

The tendency for larger trees to exhibit lower values of $\overline{RGR}$ has been explained in several ways (Brand et al. 1987). Trees accumulate a large amount of nonliving biomass in xylem tissue, which serves important structural and transport functions but does not contribute to growth per se. The proportion of biomass that is accounted for by the stem tends to increase with size (Tadaki et al. 1977, Waring and Schlesinger 1985, Britt et al. 1990). Since $\overline{RGR}$ is a measure of growth per unit total weight, an increase in stem weight would tend to decrease $\overline{RGR}$ as size increases. Furthermore, as trees grow, self-shading of foliage and the smaller ratio of photosynthetic to respiring tissue may result in lower $\overline{RGR}$. Thus, it should be expected that $\overline{RGR}$ would decrease with tree size.

The data in Figure 1 suggest that biomass and $\overline{RGR}$ are confounded. In general, the $\overline{RGR}$ of trees from both treatments tended to decrease with time. In most cases, the largest ideotype trees also exhibited the lowest $\overline{RGR}$ within a treatment and year. Brand et al. (1987) suggest that the ontogenetic drift associated with $\overline{RGR}$ can be eliminated by calculating the mean relative production rate. However, with our data, the same ontogenetic drift was present when comparing treatment differences in mean relative production rates. However, the problems of data interpretation caused by ontogenetic drift can be removed by changing the basis of comparison from trees of equal age to trees of equal biomass (i.e., Figure 2). Similar approaches have been reported for *Impatiens parviflora* D.C. (Hughes and Evans 1963); *Dactylis glomerata* L. (Eagles 1969); and *Achillea millefolium* L. (Bourdot et al. 1984). Each of these authors found that a comparison based on equal dry weights significantly changed the relationship of the growth analysis curves and subsequently their interpretation of the results.

Figure 2 presents $\overline{RGR}$ of trees as a function of their biomass. These data clearly show that the $\overline{RGR}$ of trees in the low weed-abundance treatment was greater than those which were grown in the presence of weeds. All ideotypes fell on the same curve. Seedlings with large diameters simply had an advantage of size over seedlings with small diameters, and the advantage was maintained as the stand developed. The data show no interactions between weed control and initial seedling diameter. Although this data set was amenable to the analysis of growth trends as a function of tree biomass, this type of analysis should be done with caution on other data sets, particularly those that compare tree growth within a
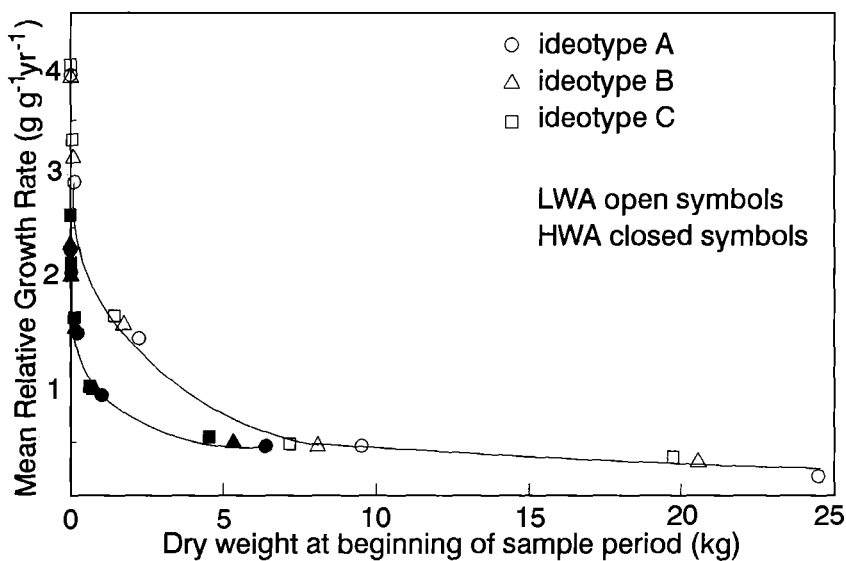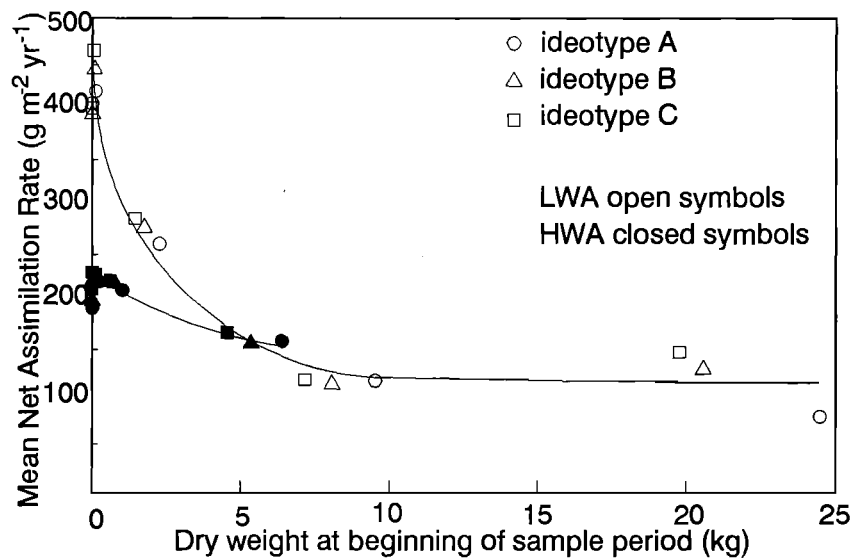
FIGURE 2. Relationship between mean relative growth rate and seedling dry weight at the beginning of each sample period. Treatments are defined as in Figure 1.

season. Trees growing at different rates but compared at the same biomass will be compared at different points in time.

Radosevich and Osteryoung (1987) suggest that classical growth analysis may be used to better understand the growth responses as well as the changes in tree structure and function that are influenced by vegetation management. This can be
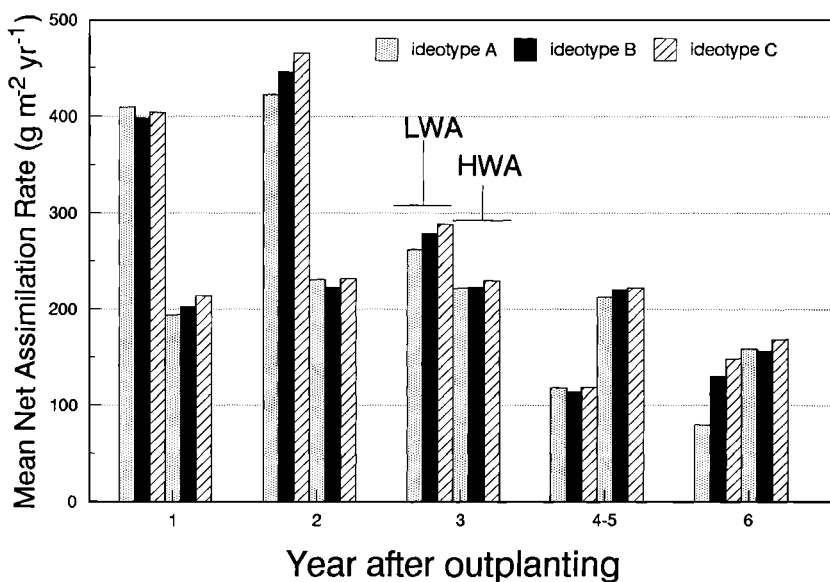
FIGURE 3. Mean net assimilation rate for three seedling ideotypes grown with (*HWA*) and without (*LWA*) herbaceous weed interference for the first 6 years after outplanting. Treatments are defined as in Figure 1.
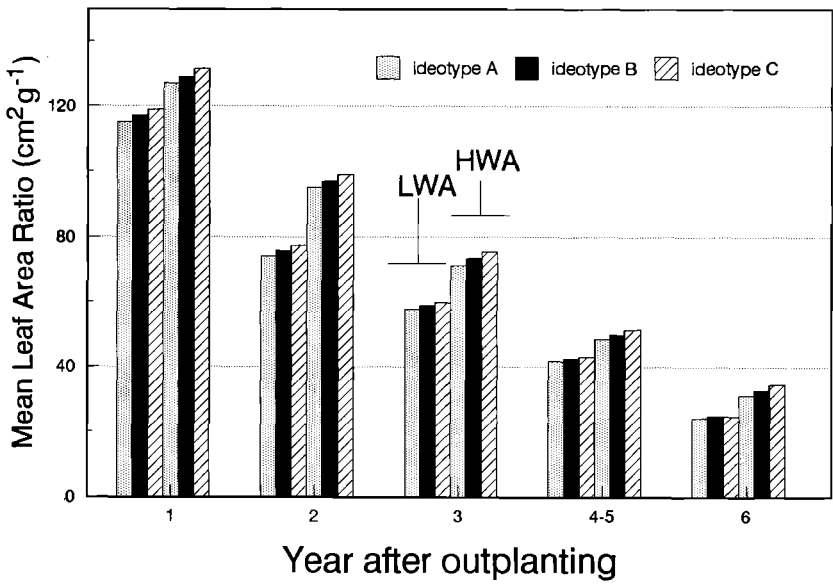
FIGURE 4. Mean leaf area ratio for three seedling ideotypes grown with (*HWA*) and without (*LWA*) herbaceous weed interference for the first 6 years after outplanting. Treatments are defined as in Figure 1.

done by separating $\overline{RGR}$ into a "physiological" component ($\overline{NAR}$) and a "morphological" component ($\overline{LAR}$). When $\overline{NAR}$ is plotted against time, the weight gained per unit of leaf area increased substantially for trees in the low weed interference plots during the first 2 years (Figure 3). Differences diminish in year 3, and substantial reductions in $\overline{NAR}$ are observed in years 4–6 (Figure 3).

FIGURE 5. Relationship between mean net assimilation rate and seedling dry weight at the beginning of each sample period. Treatments are defined as in Figure 1.
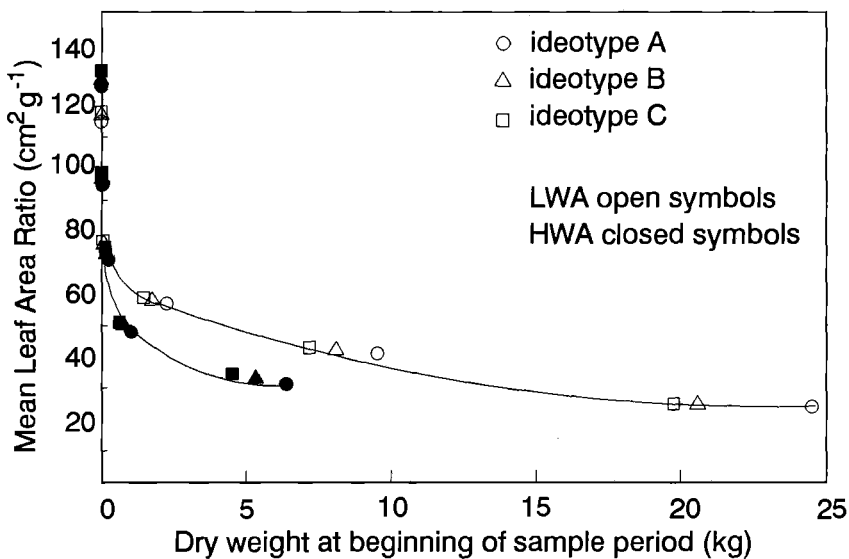
FIGURE 6. Relationship between mean leaf area ratio and seedling dry weight at the beginning of each sampling period. Treatments are defined as in Figure 1.

However, $\overline{LAR}$ appears to be reduced when weed interference is eliminated (Figure 4). These trends differ somewhat when trees of the same biomass are compared. $\overline{NAR}$ is substantially increased throughout the range in data present for trees of comparable biomass (Figure 5) for trees less than 5 kg; however, the data suggest that the lines are converging, or possibly $\overline{NAR}$ is decreased somewhat compared to trees in the *LWA* treatment when they reach approximately 5 kg. $\overline{LAR}$, on the other hand, shows only minor differences at smaller sizes, but the $\overline{LAR}$ appears to be diverging with increasing biomass (Figure 6).

Caution should be exercised when interpreting these data since only aboveground biomass was quantified. Nevertheless, these data do show differences in the temporal importance of aboveground growth per unit of leaf area and the partitioning of leaf area in contributing to the growth responses observed. Additional research is needed to more completely understand how multiple stresses induced by competition influence carbon partitioning patterns. Yet, these data show apparent differences in carbon partitioning as a result of reductions in competition. Furthermore, the increased propensity to partition carbon into leaf area is an important factor in the observed responses.

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