FIRST YEAR GROWTH, BIOMASS YIELD, AND LEAF AREA DEVELOPMENT OF FOUR INTENSIVELY-CULTURED *POPULUS* CLONES IN SOUTHERN MICHIGAN[1]

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ABSTRACT

Unrooted cuttings of four hybrid Populus clones were planted in May 1977 at 1.0 x 0.33 m spacing. Growth and leaf area development of the clones were measured periodically throughout the growing season. After the onset of dormancy in the fall, final growth and biomass yield values were obtained from 4.0 x 4.0 m plots. Linear regressions of cubic volume (D^2H) versus dry weight of harvested stems showed r^2 values $\geq$ 0.95. Dry weights of unharvested stems were then estimated using prediction equations developed from the linear regressions. Total above ground biomass produced in the first year varied from 3.2 to 5.6 t/ha, with leaf biomass representing 29 to 37% of the total. Biomass of wood plus bark varied from 2.2 to 3.5 t/ha. Average height of the trees ranged from 1.2 to 1.3 m. Leaf area index (LAI) peaked at 1.4 to 2.5 m^2/m^2, while leaf area per tree varied from 0.47 to 0.84 m^2. Leaf area ratio (LAR) and leaf weight ratio (LWR) were initially high and decreased throughout the growing season; LAR ranging from 115 to 35 cm^2/g and LWR varying from 0.75 to 0.29. Specific leaf weight (SLW) tended to increase throughout the growing season, varying from 5.5 to 8.7 mg/cm^2. Evidence is presented to support the use of SLW in combination with LAI as predictors of first-year biomass yield in poplar.

INTRODUCTION

With demands for wood increasing and commercial forest land decreasing, much interest has developed in producing wood fiber or biomass by means of short-rotation, intensive culture of hardwoods (McAlpine et al. 1966, Schreiner 1970). Hybrid poplars have the potential to adapt to and be very productive under intensive culture systems (Heilmann et al. 1972, Dickmann 1975). The experiment described here is designed to provide further data on the physiology and biomass production of hybrid poplar under intensive culture. The results discussed were obtained during the first growing season of a planned 3-year rotation.

MATERIALS AND METHODS

Experimental Design

The general plot layout is a randomized complete block design with four replications. Each replication contains three plots of one poplar hybrid. The three plots in each replication will be harvested according to the following schedule: one plot will be allowed one year of growth from planting, then cut, followed by two years of coppice regrowth; one plot will grow for two years before cutting, followed by one year of coppice regrowth; the third plot will grow for three years before cutting. This schedule will allow us to assess the productivity of various combinations of growth during the initial three years following establishment.

[2] USDA Forest Service, Northeastern (NE) or North Central (NC) Forest Experiment Station numbers.

The individual plots were 6 m wide (E-W) and 8 m long (N-S). Each plot consisted of nine east-west rows spaced one m apart, with spacing within the rows of 0.33 m, giving a maximum plant density of 30,303 trees/ha (12,263 trees/acre). Two rows were used for periodic growth analysis harvests and four rows were used for determination of leaf area index and biomass. At least one border row or three border trees within a row were located around the harvested subplots. Plots were separated by buffer strips of 6 m (N-S) and 5 m (E-W).

Cultural Methods

Unrooted, dormant cuttings were planted in early May 1977. Hybrid clones NE 353[2] (*P. deltoides* X *P.* 'caudina'), NE 48 (*P. maximowiczii* X *P.* 'berolinensis'), NE 58 (*P.* 'rasumowskyana' X *P.* 'incrassata'), and NC 5326 (*P.* X *euramericana* 'eugenii') were planted with each replication containing a different clone.

Weed control was accomplished by spraying 2.8 kg/ha of simazine and 18.7 l/ha of amitrole-T two weeks prior to planting. All of the plots were fertilized with 224 kg/ha of 10-20-20 granular fertilizer on May 17 and an additional 75 kg/ha of ammonium nitrate (33-0-0) on August 1. Irrigation was not used. The soil types present are a well-drained, slightly eroded Kalamazoo sandy loam (a fine-loamy, mixed, mesic Hapludalf), with a 0-2% slope and a sandy clay loam to clay loam subsoil, and a well drained, slightly eroded Hillsdale sandy loam (a coarse-loamy, mixed, mesic Hapludalf), with a 2-6% slope and a sandy clay loam or loam subsoil.

Experimental Methods

Growth Analysis Harvests: Beginning on June 23 and continuing every two weeks until September 27, a sub-subplot of two trees was selected at random within the growth analysis subplot and harvested. Stem height and diameter at 5 cm were measured prior to harvesting. The trees were partitioned into stem and leaves, and total leaf area per tree was measured to the nearest cm^2 using a Li-Cor Model LI-3000 leaf area meter and Model LI-3050A belt conveyor. In addition, individual leaf areas were measured to the nearest 0.1 cm^2 along with the leaf length to the nearest 0.1 cm. The stem and leaves were oven-dried at 75°C and weights determined. Growth analysis parameters were calculated using equations from Ledig (1974).

Leaf Area Index: The ratio of leaf surface area of a plant canopy to ground surface area is the leaf area index (LAI). LAI determinations were conducted on a ten-tree sub-subplot within the biomass subplot. At two-week intervals, stem height, diameter at 5 cm, and lengths of all leaves present on these trees were measured. A leaf marking system was employed so that only new mature and immature leaves had to be measured each time. Old leaves were accounted for by counting and recording presence or absence of the leaves.

A least squares regression of leaf length (LL) versus leaf area (LA) of the same form as reported by Larson and Isebrands (1972) was developed for each clone, using leaf length and area values for individual leaves. The form of the regression equations was: $\ln LA = b + m(LL) + n(\ln LL)$. Regressions for all clones had R^2 values ≥ 0.97 (Table 4). Student's t-tests performed on all possible pairs of coefficients from the different clones were all not significant at $\alpha = 0.05$, indicating no clonal differences between coefficients, despite differences in leaf shape. Leaf area of each leaf present on the tree was then calculated using the prediction equation for that clone. The area of all the leaves on the tree were summed, the total leaf area of all ten trees summed, and this total divided by the ground area to obtain LAI.

Biomass Harvests: After the onset of dormancy and leaf abscission in the fall, the biomass subplots were harvested. Stem height and diameter at 5 cm were measured prior to harvesting. The biomass yield of wood and bark was obtained by totaling the weights of all the stems, converting to tons, and dividing by the plot area. The total above ground biomass was then calculated by using the leaf weight ratios from the September 27th growth analysis harvest to estimate the leaf biomass produced.

Individual stem height (H), diameter (D), and dry weight (DW) values were used to develop a least squares regression of volume (D^2H) versus dry weight for each clone (Zavitkovski 1971, 1974). The form of the regression equations was: $DW = b + m(D^2H)$. All regressions had r^2 values ≥ 0.95. Due to lack of homogeneity of variance values, however, it was not possible to test for clonal differences in slope of the regressions. Heights and diameters of stems in the remaining unharvested plots were measured and dry weights of the stems and biomass yield of wood and bark calculated using the prediction equation for that clone. Total above-ground biomass was then calculated in the same manner as in the harvested plots.

RESULTS AND DISCUSSIONS

Growth and Biomass Yield

Height and Diameter Growth: First year height growth began shortly after planting and continued until terminal bud formation occured in late August. Clone NE 48, however, did not set bud until late September (Figure 1). Average height of the four clones (Table 1) was greater than heights reported by Ek and Dawson (1976) and Dawson et al. (1976) and about the same as heights given by Bowersox and Ward (1976, 1977). However, the average basal diameters were larger for our plots than the diameters reported by these authors (Table 1). Diameter growth in this study was depressed by soil moisture deficits in the latter half of August, but recovered with increased soil moisture in September (Figure 2). Survival of all clones was excellent (Table 1) and similiar to survival after one year reported by Bowersox and Ward (1976)

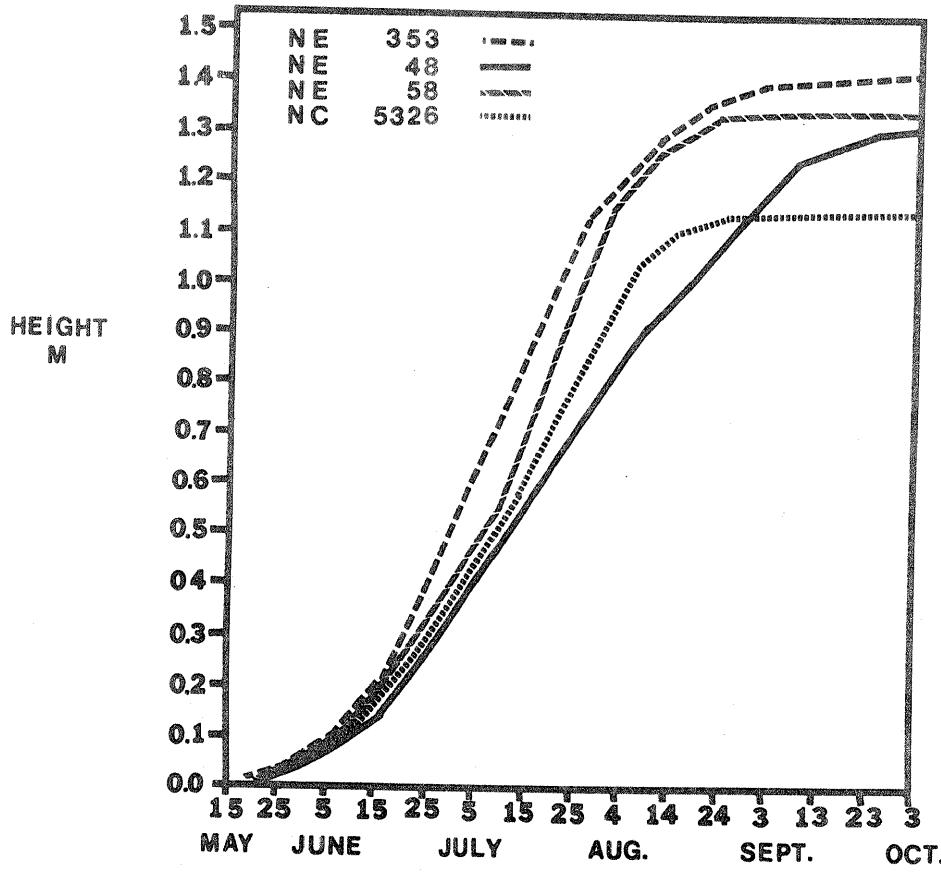

Figure 1. Cumulative height growth of four hybrid poplar clones during the first growing season.

Table 1. Height, diameter, and survival of four hybrid poplar clones after one growing season.

Clone Number	Harvested Plot			Average of all Plots		
	Height (m)	Diameter[a] (cm)	Survival (%)	Height (m)	Diameter[a] (cm)	Survival (%)
NE 353	1.27	1.3	100.0	1.34	1.2	98.6
NE 48	1.29	1.4	98.2	1.18	1.2	98.4
NE 58	1.32	1.2	99.4	1.24	1.2	99.2
NC 5326	1.18	1.2	94.7	1.25	1.2	95.3
AVERAGE	1.26	1.3	98.1	1.26	1.2	97.9

[a]Diameter was measured 5 cm above ground level or emergence from cutting.

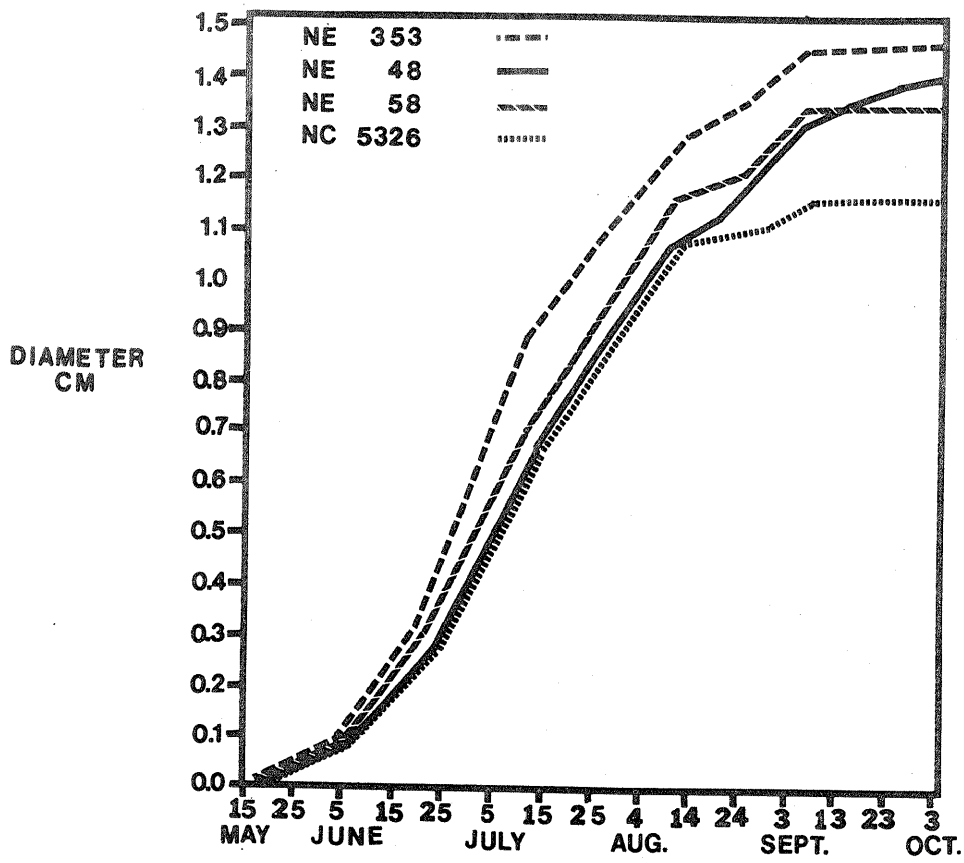

Figure 2. Cumulative diameter growth of four hybrid poplar clones during the first growing season.

Biomass Yield: Actual biomass yield of wood and bark in the harvested plots ranged from 1.6 to 2.9 t/ha (Table 2). With leaves added, biomass yields increased to 2.4 to 4.6 t/ha. Estimates of biomass yields using the prediction equations ranged from 2.2 to 3.5 t/ha for wood and bark and 3.2 to 5.6 t/ha for total above ground biomass. Differences in yield between plots of a single clone can be attributed largely to site variation over the study area.

Numerous reports of wood and bark biomass and total above ground biomass production of hybrid poplars are present in the literature (Heilmann et al. 1972, Crist and Dawson 1975, Dawson et al.1976, Anderson and Zsuffa 1975, Bowersox and Ward 1976, 1977, Baker and Blackmon 1977, Switzer et al. 1976, Ek and Dawson 1976). Stands older than one year produced from 6 to 19 t/ha/year. One-year-old stands at similar spacings produced from 0.3 to 5.7 t/ha of wood and bark and up to 8.6 t/ha of total above ground biomass. The experiment of Bowersox and Ward (1976, 1977) is most closely comparable to our study. Despite having similar height values after one year, the larger yield of wood and bark in our plots is due in part to the somewhat larger average basal diameters achieved by our trees. Bowersox and Ward (1976) also thinned down to one stem per cutting, whereas our four clones averaged 1.7 to 1.9 stems per cutting. Having these additional stems present decreased average height and diameter values of primary stems, but also increased LAI and biomass production.

Leaf Area Development

Leaf Area Index: Maximum LAI's of the four clones varied from 1.4 to 2.5 m^2/m^2 (Table 5, Figure 3). Despite several periods of senescence and abscission of lower leaves due to water stress, LAI seasonal curves continued to increase until bud formation. Shortly after bud formation but prior to autumn leaf fall, LAI curves reached a plateau (Figure 3). Again, clone NE 48 had a later plateau than other clones due to its later bud formation.

Average leaf area for trees sampled for LAI determination ranged from 0.47 to 0.84 m^2 (Table 5). As expected, the higher LAI's correspond with the higher average leaf areas per tree. Clone NE 353, for example, had four times as many leaves as any of the other clones, and a substantially higher LAI. NE 353 also produced a large number of lateral branches with small leaves, whereas the other clones only produced an occasional lateral branch. It is the large number of small lateral branch leaves that gave NE 353 its higher leaf area per tree and LAI. For NE 353 the average individual leaf area was 28 cm^2 while the other clones varied from 60 to 85 cm^2, demonstrating the effect of the smaller leaves produced on lateral branches. Pollard (1970) and Isebrands et al. (1977) both showed similiar patterns of small-sized leaves on lateral branches.

Table 2. Actual and estimated biomass yields in t/ha of four hybrid poplar clones after one growing season.

Clone Number	Harvested Plot		Average of Estimated Plots	
	Wood and Bark	Wood and bark and leaves	Wood and Bark	Wood and Bark and leaves
NE 353	2.9	4.6	3.5	5.6
NE 48	2.6	3.7	2.3	3.2
NE 58	1.9	2.8	2.2	3.2
NC 5326	1.6	2.4	2.2	3.3
Average	2.2	3.4	2.6	3.8

Table 3. Regression and prediction equation parameters from D^2H versus dry weight regressions.[a]

Clone Number	Regression		Intercept	Coefficient	
	Significance of F-Ratio[b]	r^2 value	(b)	(m)	Significance of t value[b]
NE 353	**	0.952	2.54	0.182	***
NE 48	**	0.983	3.33	0.153	***
NE 58	**	0.980	4.04	0.155	***
NC 5326	**	0.976	3.44	0.149	***

[a]Prediction Equation $DW = b + m (D^2H)$, DW = dry weight, D = diamter, H = height

[b]ns not significant at 0.05 level
* significant at 0.05 level
** significant at 0.01 level
*** significant at 0.001 level

Table 4. Regression and prediction equation parameters from leaf lengths versus leaf area regressions.[a]

Clone Number	Regression		Intercept (b)	Coefficients			
	Significance of F-Ratio[b]	R^2 value		Variable 1 (m)	Significance of t value[b]	Variable 2 (n)	Significance of t value[b]
NE 353	**	0.974	-1.48	-0.0542	**	2.65	***
NE 48	**	0.983	-1.04	0.0594	***	1.87	***
NE 58	**	0.985	-1.72	-0.0291	*	2.64	***
NC 5326	**	0.986	-1.37	-0.00096	ns	2.36	***

[a]Prediction Equation: $\ln LA = b + m (LL) + n (\ln LL)$, LA = leaf area, LL = leaf length

[b]ns not signficant at 0.05 level
* significant at 0.05 level
** significant at 0.01 level
*** significant at 0.001 level

Table 5. Leaf area characteristics of four hybrid poplar clones in early September after one growing season.

Clone Number	Leaf Area Index (m^2/m^2)	Leaf Area/Tree (m^2)	No. of leaves/Tree
NE 353	2.5	0.837	302
NE 48	1.4	0.469	79
NE 58	1.9	0.632	75
NC 5326	1.6	0.530	78

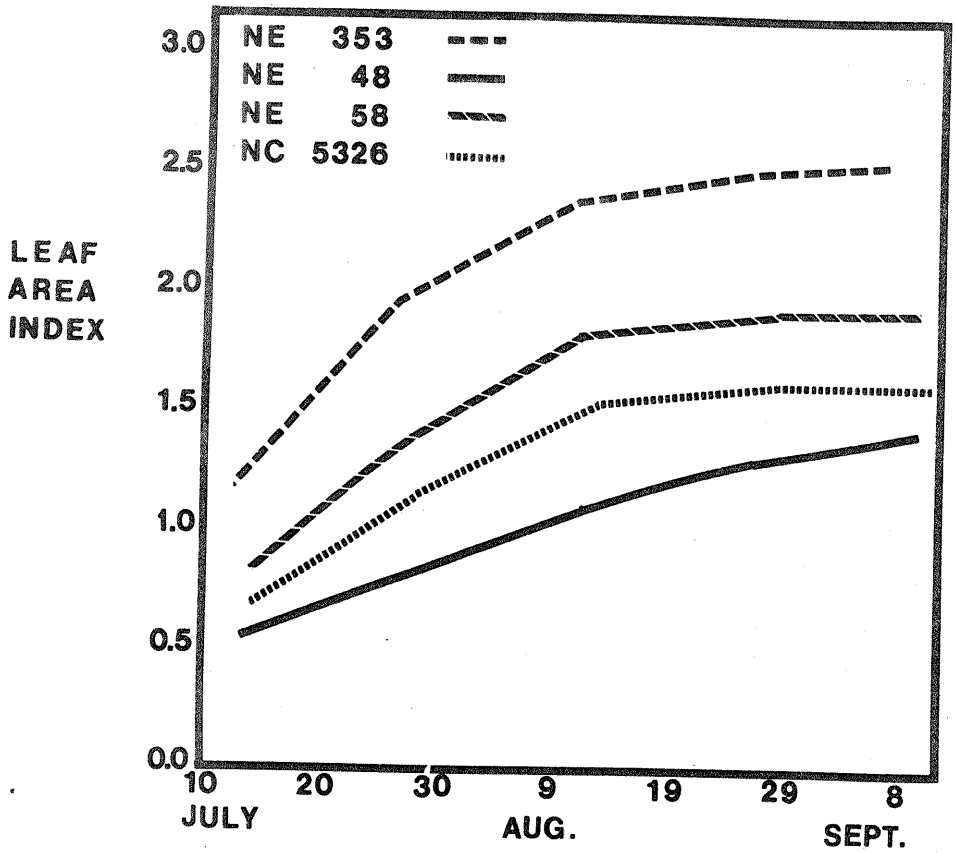

Figure 3. Leaf area index (LAI) of four hybrid poplar clones during the first growing season.

LAI has been shown to be one of the most important and easiest to manipulate of the determining factors of crop yield (Watson 1956). Larson and Isebrands (1972) have shown that photosynthetic leaf area is highly correlated with wood yield in Populus. Stands maintaining higher LAI's should produce higher yields, other factors being equal. For all clones except NE 48 in our study, the relationship holds. As LAI increased, biomass yield of the clones increased. Clone NE 48, however, had the lowest LAI but the second highest biomass production.

LAI of a six-year-old natural aspen sucker stand was 2.5 m^2/m^2 (Pollard 1970), whereas three-year-old intensively-cultured hybrid poplar stands varied from 4.0 to 7.5 m^2/m^2 and four-year-old stands from 15.6 to 44.8 m^2/m^2 (Isebrands et al. 1977). The large increase in LAI of intensively-cultured stands is one of the factors responsible for the increased biomass productivity in these stands over natural stands.

Growth Partitioning: Leaf area ratio (LAR) is the ratio of leaf area to total dry weight of the plant. Larson and Isebrands (1972), Jarvis and Jarvis (1964), and Pollard and Wareing (1968) all present LAR or similar data for Populus that show a decrease in LAR with increasing size of the tree or seasonal progression. Our data for LAR also show the same decrease with increasing tree size (Figure 4). LAR values in our study are similiar to those cited above.

Leaf weight ratio (LWR), the ratio of leaf weight to total dry weight of the plant, is the decimal equivalent of the percentage of total biomass partitioned into leaves. LWR also showed a decrease with increasing tree size or seasonal progression (Figure 4). Data presented in Larson and Isebrands (1972) and Switzer et al. (1976) also show a decreasing LWR with increasing tree size or age. The LWR of one-year-old cottonwood in Mississippi was 0.37 (Baker and Blackmon 1977), which is similar to the LWR values for our clones at the end of the first growing season.

The high LAR and LWR values of poplar cuttings early in the season is a significant factor in their establishment and early growth. The high partitioning of weight into leaves, over 70% in some clones, provides a large photosynthetic surface upon which further growth is based. In fact, the rapid growth of young hybrid poplars and cottonwood can be attributed to this large initial investment in leaves. As the season progresses and the plants become established in the soil, a greater proportion of biomass is partitioned into the stem, and the proportion of leaves drops (to about one-third in our study). This trend continues as poplar stands develop, until, for example, at 20 years only 3 to 4 percent of the weight is in foliage and nearly 90 percent in stems (Switzer et al. 1976). Thus, rotations longer than one or two years are desirable to increase the proportion of wood, the most useful dry weight component.

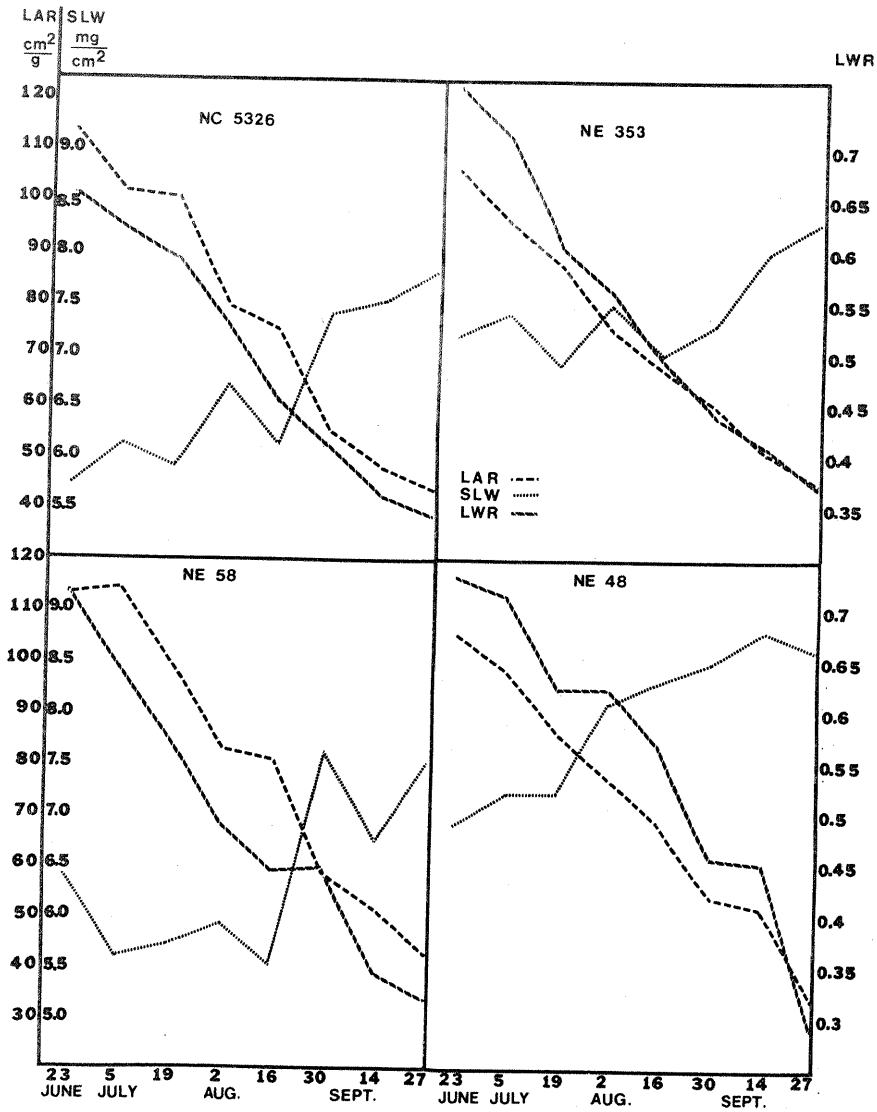

Figure 4. Seasonal progressions in leaf area ratio, (LAR, cm^2/g), specific leaf weight (SLW, mg/cm^2), and leaf weight ratio (LWR) of four hybrid poplar clones.

Specific leaf weight (SLW), the ratio of leaf weight to leaf area, is also the inverse of specific leaf area (SLA). SLW is a measure of the thickness or density of the leaf per unit area. Recent thought has SLW playing as important a role in determining yield as LAI. Crops having the same leaf surface area but different leaf thicknesses can differ substantially in productivity, because thicker leaves have a larger actual photosynthetic cell area when light is not limiting than thin leaves (Pieters 1960, Kallis and Tooming 1974). Our data support this idea.

SLW fluctuated substantially, but showed an increasing trend over the growing season (Figure 4). Leaves became heavier, and, probably, thicker with age. Clone NE 353, the most productive clone, had relatively high SLW's throughout the growing season along with the highest LAI's. Clone NE 48 consistently showed the highest SLW's, as evidenced by the thick leathery appearance of the leaves, and the lowest LAI's, but ranked second in biomass productivity. The low LAI of NE 48 may be an adaptation to allow maximum light penetration to the lower canopy, allowing its thick leaves to photosynthesize most efficient

The values of SLW obtained in this study correspond to those reported by others. SLW's in natural aspen stands varied from 6.8 to 8.3 mg/cm^2 in old trees and from 10.4 to 12.6 mg/cm^2 in 6-year-old-suckers (Pollard 1970, Zavitkovski 1971). Jarvis and Jarvis (1964) report SLW values of 2.1 to 7.0 mg/cm^2 for *P. tremula* grown in sand culture. Isebrands *et al*. (1977) give SLW values of 9.6 to 11.4 mg/cm^2 for four three-year-old poplar clones, and within the crown of five-year-old *P.* 'Tristis #1', SLW decreased from 9.3 to 2.8 mg/cm^2 from top to bottom.

CONCLUSIONS

The data of this paper illustrate the high potential productivity of fertilized, unirrigated, close-spaced hybrid poplar plantations in southern Michigan. Even during the first year, yield equivalents of 1.6 to 3.5 t/ha of stem wood (1.5 to 3 cords/acre) are impressive. Yearly biomass increments will undoubtedly rise substantially in subsequent years as the trees more fully occupy the site (Bowersox and Ward 1976). If intensive culture plantations are established close to sites of utilization, and if plantations are held until mean annual biomass increment reaches a maximum, an economic alternative to conventional silviculture appears to exist.

These data also indicate the importance of a large leaf surface and full utilization of the growing season to first-year biomass productivity in poplar. Clone NE 353 produced more biomass than any other clone. Its greater photosynthetic potential was shown by its consistently high LAI values and moderately high SLW. Clone NE 48 demonstrated a different growth strategy. Its LAI was low, but SLW's were higher than any other clone. In addition, it continued to grow until early October, thus gaining a month of growth over the three other clones studied.

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