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ACCUMULATION AND DISTRIBUTION OF DRY MATTER AND NUTRIENTS IN AIGEIROS POPLAR PLANTATIONS[1/]

G. L. Switzer, L. E. Nelson, and James B. Baker[2/]

Abstract.--Patterns of accumulation of dry matter and nutrients through 20 years in Aigeiros poplar plantations are strongly influenced by mode of plantation culture. Accumulation of both dry matter and nutrients in closely spaced thinned plantations is linear through age 12 to 14, after which accumulation declines and then stabilizes. In contrast, dry matter and nutrient accumulation in the widely spaced unthinned plantations accelerates through age 10 and is linear throughout the remaining 10 years. At 20 years the dry matter production of the close and widely spaced plantations is 21 and 36 percent greater, respectively, than natural stands. The stems of the widely spaced unthinned plantations contain greater quantities of all nutrients at harvesting than the other cultural systems, thus causing greater nutrient drain. Black poplar plantations have twice the nutrient requirements of loblolly pine plantations through age 16. Debarking on the site is suggested to conserve nutrients.

Additional keywords: Populus deltoides, Euramericana hybrids, Pinus taeda, plantation management.

Intensive management of poplar stands has resulted in shortened rotations, increased tree utilization, use of a site for one species or even for a single clone, reduced competition--particularly during establishment and early development--and modification of soil-site properties (Switzer and Nelson 1973, Bunn and Will 1973). How these intensive management practices influence the continued productivity of black poplar sites is uncertain, but basic information about stand nutrition is necessary. This paper reports accumulation and distribution of dry matter (biomass) and nutrients in natural poplar stands and in plantations managed under two spacing-thinning regimes.

METHODS

Data were available from both natural stands and plantations of Populus deltoides Bartr. in the Lower Mississippi River Valley (United States) and from plantations of Euramericana hybrids from the Po River Valley (Italy).

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[2/]Switzer, Forester, and Nelson, Agronomist, Mississippi Agriculture and Forestry Experiment Station, Mississippi State University, Mississippi. Baker, Soil Scientist, Forest Service - USDA, Southern Forest Experiment Station, Stoneville, Mississippi.

All stands were on good sites (site index 37-40 m at age 30 years) and are described as follows:

(1) Natural stands of eastern cottonwood (data from Williamson 1913).--These stands, located in the Lower Mississippi Valley, are unthinned and have a stocking of about 3,000 stems/ha at age 5. Natural mortality reduces this stocking to 300-400 stems/ha at age 20, at which time mean diameter is about 30 cm.

(2) Closely spaced thinned plantations of eastern cottonwood (data from Mueller 1976).--These plantations are typical of those established at close spacings (3 x 3 m) in the Lower Mississippi Valley during the last two decades with cuttings obtained from bar-run sources. The plantations are cultivated the first year and at the end of the first growing season contain about 750 stems/ha. At age 20--after three thinnings at approximately 5-year intervals beginning at age 5--stocking is about 200 stems/ha and mean diameter 40 cm. The first thinning usually removes one-half of the trees, and the two subsequent thinnings remove about one-third of the residual trees.

(3) Widely spaced unthinned plantations of Euramericana hybrids (data from FAO 1958).--These plantations are in the Po River Valley of Italy and are established at a wide spacing (5 x 8 m) with 2-year-old planting stock at 250 stems/ha; they receive no thinning. In this region, such plantations are usually irrigated and sometimes fertilized; they are normally intercropped for the first 3 years, hayed through 7 years, and support grazing until age 20, when mean diameter is about 50 cm.

Estimation of Dry Matter (Biomass)

Dry matter in the natural stands was estimated by first calculating stem dry matter, using Williamson's (1913) volumes and Mueller's (1976) stem specific gravities. Total stand mass was then estimated as a proportion of stem mass according to dry matter distribution data from Mueller (1976). Next, the total mass was partitioned into the remaining components as follows: foliage mass was determined by combining individual tree data from Carter and White (1971) and Mueller (1976); branch weight was then calculated as the difference between stems plus foliage and total dry weight. The same procedure for estimating dry matter was applied to the widely spaced unthinned plantations. Stem volumes and specific gravities were obtained from FAO (1958); foliage weights were derived from the data of Frison (1969). The dry weights obtained by this method are probably slightly underestimated since tree volumes reported were based on top diameters of 10 cm.

Dry matter and distribution values for closely spaced thinned plantations were based on Mueller's data (1976), obtained by the mean tree method of estimation.

Estimation of Nutrients

Nutrient contents and nutrient accumulation for branches, for stems, and for leaves were derived by multiplying each component's dry weight times the concentration of each nutrient (N, P, K, Ca, Mg). The concentrations of each nutrient were obtained by averaging the data of Carter and White (1971), Baker and Randall (1975), and Blackmon and White (1972) for eastern cottonwood in the United States, and Frison (1969) for Euramericana hybrids in Italy. It is recognized that the quantities obtained by this procedure are only approximate, since the effects of soil, climate, age, and clone on nutrient concentration have been ignored.

RESULTS AND DISCUSSION

Dry Weight Accumulation (Biomass)

For unthinned natural stands (Lower Mississippi Valley), dry matter accumulation (biomass)accelerates through age 7, maintains a linear rate through age 13, then declines as the mass of the standing crop stabilizes (Figure 1). Thus, in natural stands, the pattern of dry matter accumulation accelerates for about one-third of the 20-year period, becomes linear for another third, and remains stable for the final third. Both plantation cultures differ markedly from this pattern. For closely spaced thinned plantations (Lower Mississippi Valley), accumulation is rapid and linear through age 14, after which productivity stabilizes. In contrast, the rate of dry matter accumulation of the widely spaced unthinned plantations (Po Valley) accelerates through about age 10 and is linear to age 20.

Thus, the pattern of dry matter accumulation of closely spaced unthinned plantations differs most from that of natural stands in the early years; whereas productivity of widely spaced unthinned plantations differs most from that of natural stands late in the 20-year period. For example, through age 8, dry matter accumulation of closely spaced thinned plantations is at least 100 percent greater than that of natural stands; however, after age 8, the difference declines and is only about 20 percent greater at age 20. On the other hand, the productivity of the widely spaced unthinned plantations, which is 30 to 50 percent less than that of natural stands through age 16, exceeds natural stand productivity by about 40 percent by age 20.

The same trends are evident for both periodic and mean annual increments (Figure 2). The closely spaced thinned plantations achieve maximum periodic rate of dry matter accumulation (about 35 tons per biennium) between ages 6 and 8; whereas, maximum rates of natural stands and widely spaced plantations occur at age 10-11 and 16-20 years, respectively. Although natural stands reach a maximum periodic rate of about 45 tons per biennium, this high rate is sustained for a shorter period than is true for either of the two plantation cultures. Maximum rates of about 35 tons/biennium are attained for plantations managed under both cultures; however, maximum periodic accumulation occurs nearly 10 years earlier for closely spaced thinned plantations than for widely spaced unthinned ones.

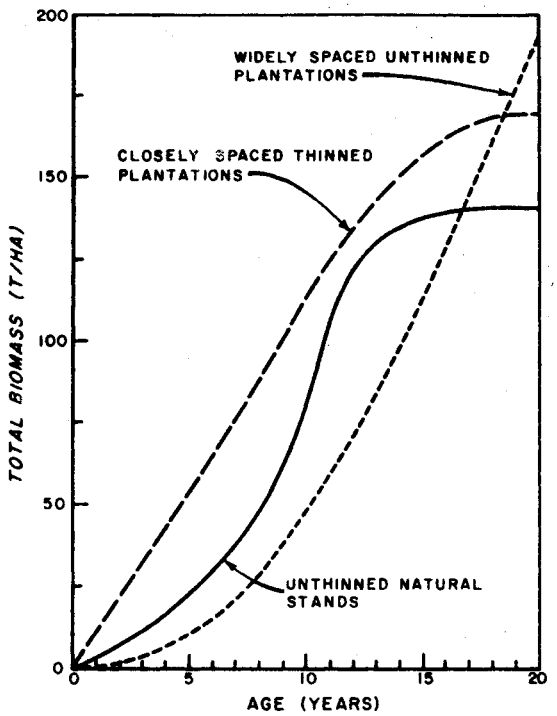

Figure 1. *Patterns of biomass accumulation in black poplar stands and plantations on good sites.*

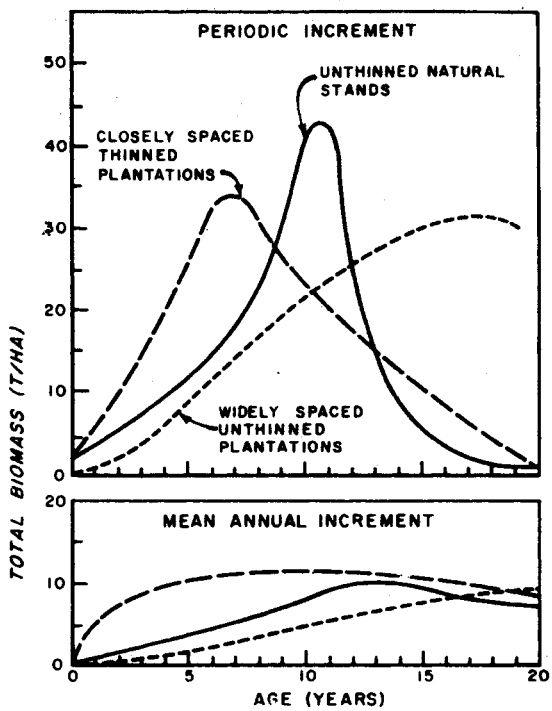

Figure 2. *Periodic and mean annual biomass increments of black poplar stands and plantations on good sites.*

The same differences are shown by the patterns of mean annual increment for the three cultures (Figure 2). Maximum mean annual increment for all three cultures is essentially the same--about 10 - 11 tons/ha. The closely spaced thinned plantations reach maximum rate earliest (about age 5), and the rate is sustained through the 20-year period, a result primarily caused by thinnings (Figure 3).

Of the total net stem production measured at age 20, 40 percent is removed by age 15 during thinnings; but thinnings did not appreciably influence total production (Table 1). For example, total net stem production at age 20 is 124 tons/ha for unthinned natural stands and is 136 tons for the closely spaced thinned plantations. However, the mean diameters of the final crop are about 30 and 40 cm, respectively--about 20 to 40 percent lower than the 50 cm attained in the widely spaced unthinned plantations.

Cultural regime also influences the quantity and distribution of dry matter among the stand components during the 20-year period (Table 1). The influence of cultural regime on dry matter accumulation is most evident in the closely spaced plantations, where thinning greatly reduces the quantity of dry matter in each component of the standing crop. The spacing and cultivation of these plantations enhances early development; for example, at age 4, they have 2.4, 3.6, and 2.2 times more dry weight in foliage, branches, and stems, respectively, than do natural stands. Furthermore, at age 4, total dry weight of closely spaced thinned plantations is more than twice as great (38.8 tons/ha) as that of the widely spaced unthinned plantations

(15.1 tons/ha); the magnitude of difference for heights and diameters of the two cultures is similar.

The influence of the three modes of culture on distribution of dry matter among foliage, branches, and stems is most evident during the early stages of development. At age 4, both the natural stands and the closely spaced plantations have about 12 percent foliage and 30 percent branches; whereas the values for the widely spaced plantings are 32 percent for foliage and 10 percent for branches. At later stages of development, these differences gradually diminish so that by age 20, dry weight is 4 percent for foliage, 8 percent for branches, and 88 percent for stems for all of the cultural regimes. Thus, the harvested portion of the standing crop--the stems--is proportionally the same at age 20 regardless of the mode of culture. Stem mass at age 20 varies from about 120 tons/ha for natural stands to about 150 tons/ha for closely spaced thinned plantations and 170 tons/ha for widely spaced unthinned plantations.

Table 1.--Influence of mode of culture and age on the total and component dry weights of black poplar stands

Age	STAND COMPONENT			TOTAL
	Foliage	Branches	Stems	
(years)	- - - - - - - - - - - - - - *tons/ha* - - - - - - - - - - - - - -			
	UNTHINNED NATURAL STANDS (Lower Mississippi Valley)			
4	2.0(13) [a/]	3.3(22)	9.8(65)	15.1
12	6.0(5)	16.7(14)	96.6(81)	119.3
20	5.6(4)	11.3(8)	124.1(88)	141.0
	CLOSELY SPACED THINNED PLANTATIONS (Lower Mississippi Valley)			
4	4.7(12)	12.0(31)	22.1(57)	38.8
12	3.4(6)	7.4(14)	43.0(80)	53.8
20	3.8(4)	7.5(8)	82.7(88) [b/]	94.0
	WIDELY SPACED UNTHINNED PLANTATIONS (Po Valley)			
4	2.2(32)	0.7(10)	4.0(58)	6.9
12	6.6(10)	6.8(10)	55.5(80)	68.9
20	6.5(3)	18.2(10)	165.3(87)	190.0

[a/] Values in parentheses are percentages of total dry weights.

[b/] In addition to this quantity the three thinnings employed in the culture of these plantations removed 53 tons of stem; thus the total stem production in 20 years is about 136 tons.

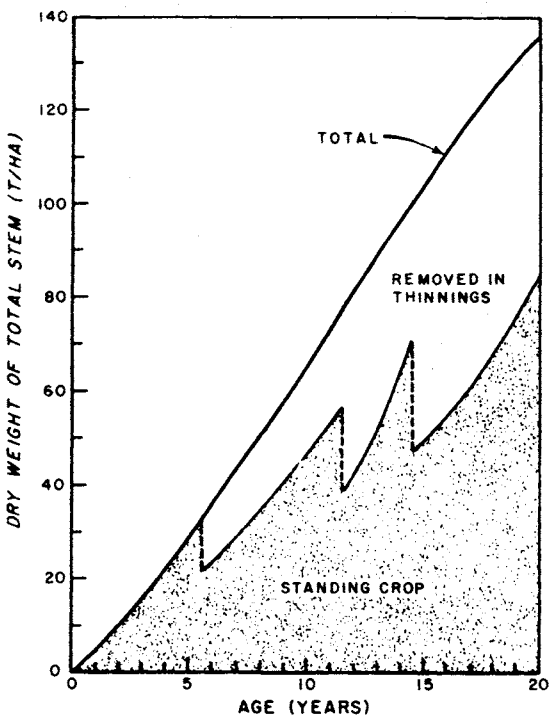

Figure 3. *Influence of thinning on distribution of total stem dry weight in closely spaced plantations of cottonwood (Lower Mississippi Valley).*

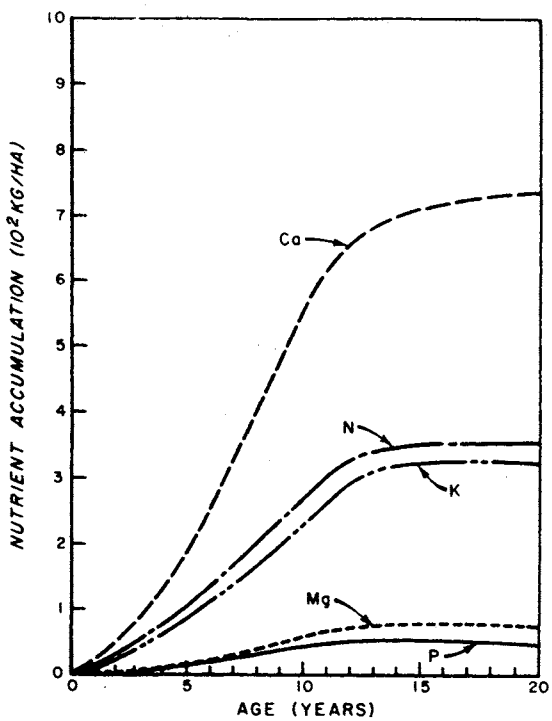

Figure 4. *Pattern of nutrient accumulation in unthinned natural stands of cottonwood (Lower Mississippi Valley).*

Nutrient Accumulation

Natural stands accumulate nutrients through age 12, when maximum levels for all nutrients are reached (Figure 4); afterwards, the quantities of nutrients in the stand stabilize. In contrast, the accumulation of nutrients in the unthinned plantations continues through age 20 (Figure 5). At age 12, when nutrient accumulation in the natural stands stabilizes, accumulation in the unthinned plantations is only 40-60 percent of the total attained at 20 years. Apparently, nutrient cycling satisfies a large proportion of the nutritional requirements of natural stands beyond age 12, whereas the cycling mechanism has not developed completely in the unthinned plantations by age 20.

Differences in periodic patterns of nutrient accumulation in unthinned natural stands and unthinned plantations were further compared by using N and Ca as representative nutrients (Figure 6). Peak rates of accumulation for these nutrients occur in natural stands between age 5 to 10 years, when the trees require about 70 kg/biennium of N and about 155 kg of Ca. The peak rates for the same two nutrients in the unthinned plantations occur between age 10 and 20 years and are about 60 kg/biennium of N and 130 kg of Ca. Thus, natural stands have slightly greater rates of accumulation than unthinned plantations. However, the period of maximum accumulation for natural stands occurs early and is of brief duration compared to plantations, which apparently achieve maximum nutrient accumulation later and for a longer period.

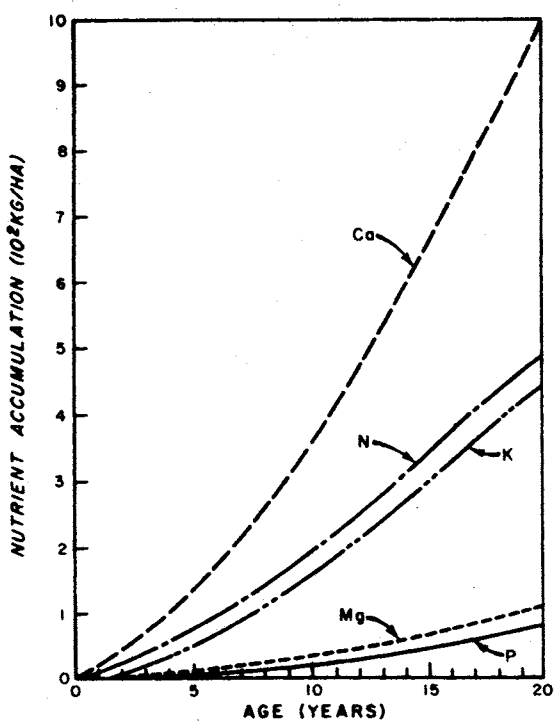

Figure 5. *Pattern of nutrient accumulation in widely spaced, unthinned black poplar plantations (Po Valley).*

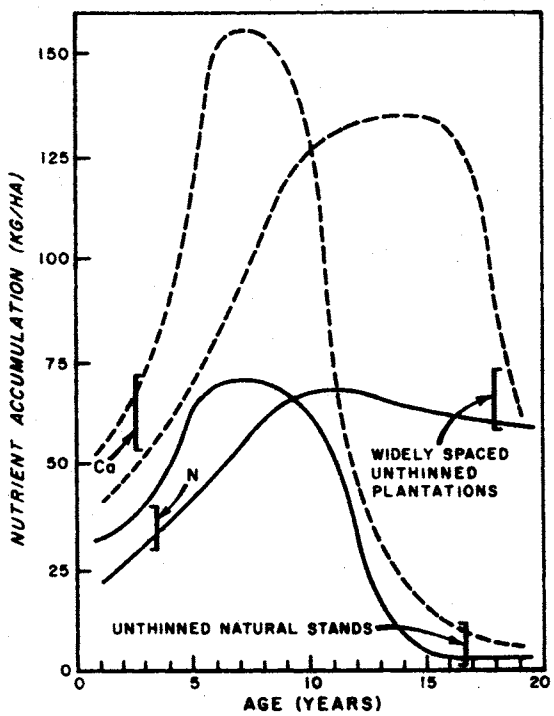

Figure 6. *Periodic accumulation of N and Ca in unthinned natural stands (Lower Mississippi Valley) and in widely spaced unthinned plantations.*

Total nutrient accumulation for both unthinned natural stands and closely spaced thinned plantations is almost identical at age 20 (Table 2). For example, unthinned natural stands accumulate 351 kg/ha of N compared to 331 kg for the closely spaced thinned plantations; the pattern for all other nutrients is the same. However, at age 20 the standing crop of natural stands contains about 30 percent more nutrients than thinned plantations because thinnings remove this amount from the plantations. For widely spaced unthinned plantations, total nutrient accumulation is 26 to 29 percent greater than for closely spaced thinned plantations and unthinned natural stands.

Stems of the widely spaced unthinned plantations contain greater quantities of all nutrients than stems of natural stands or closely spaced thinned plantations; therefore, the wide initial spacing removes the most nutrients from the site at harvest.

The patterns of nutrient accumulation to age 20 for all three cultures are essentially the same as the patterns of dry matter accumulation. These similarities are illustrated by the closely spaced thinned plantations, in which the influence of thinning on nutrient accumulation is comparable to that on dry matter accumulation. For example, thinnings removed 40 percent of the dry matter (Figure 3) and also removed 43 percent of the total nutrients, as represented by N and Ca (Figures 7 and 8). The similarity of dry matter and nutrient accumulation is also emphasized by noting that the widely spaced unthinned plantations have about 25 percent greater stem mass at age 20 than either of the other two modes of culture and contain about 25 percent more of all nutrients (Tables 1 and 2).

Table 2.--Influence of three cultural regimes on nutrient content of components of black poplar at age 20

STAND COMPONENT	NUTRIENT				
	N	P	K	Ca	Mg
	- - - - - - - - - - - - kg/ha - - - - - - - - - - - -				
UNTHINNED NATURAL STANDS (Lower Mississippi Valley)					
Foliage	93	10	61	158	15
Branches	52	8	41	93	9
Stems	206	38	230	486	55
Total	351	56	332	737	79
CLOSELY SPACED THINNED PLANTATIONS (Lower Mississippi Valley)					
Thinnings[a/]	89	16	102	205	24
Residual crop					
Foliage	75	7	44	166	11
Branches	33	5	26	59	6
Stems	134	26	149	325	36
Total	331	54	321	755	77
WIDELY SPACED UNTHINNED PLANTATIONS (Po Valley)					
Foliage	128	12	78	188	18
Branches	80	13	62	148	15
Stems	272	50	304	644	72
Total	480	75	444	980	105

[a/] Stems only.

Poplar and pine nutrient accumulation compared.--Quantities of nutrient accumulation in the poplar stands and plantations, in descending order, are Ca>>N>K>>Mg>P. This order differs from that of loblolly pine (Pinus taeda L.) stands and plantations (N>>Ca>K>>Mg>P), as described by Switzer et al. (1968) and Wells and Jorgensen (1975). Specific quantities of nutrients accumulated by these two species are shown below:

Nutrient	Black poplar[1]	Loblolly pine[2]
	- - - - - - - - - - kg/ha - - - - - - - - - -	
N	358	257
P	56	31
K	324	165
Ca	720	187
Mg	77	46

[1] These values are the means of unthinned natural stands of the Lower Mississippi Valley and Po Valley plantations, both of which have nearly equal accumulations of nutrients and standing biomass at age 16. This age was selected since it was the interval for which comparable data for loblolly pine are available.

[2] Data from Wells and Jorgensen (1975) for 16-year-old loblolly pine.

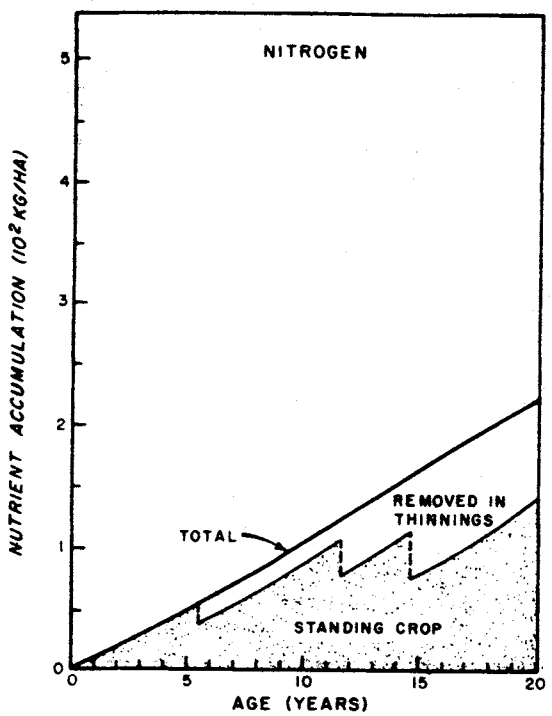

Figure 7. *Influence of thinning on the distribution of N in the stems of closely spaced plantations (Lower Mississippi Valley).*

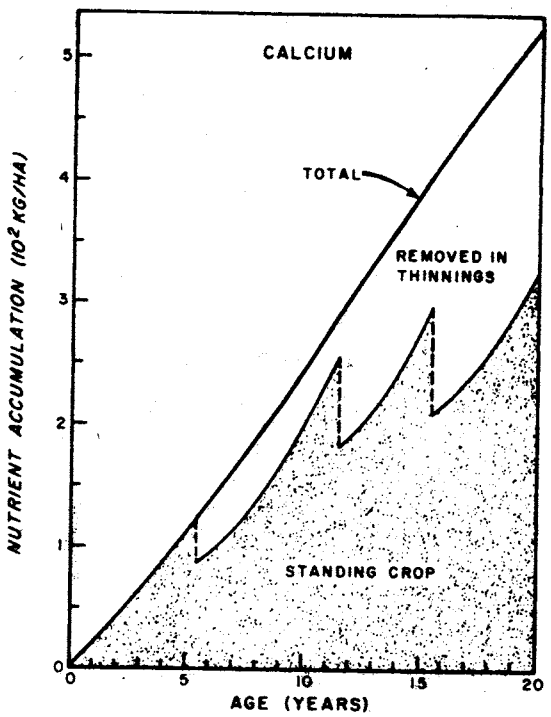

Figure 8. *Influence of thinnings on the distribution of Ca in the stems of closely spaced plantations (Lower Mississippi Valley).*

Thus, by age 16, poplars accumulate 1.4, 1.8, 2.0, 3.8, and 1.7 times more N, P, K, Ca, and Mg, respectively, than do pines. These differences in nutrient accumulation occur in stands having similar quantities of dry matter (about 145 tons/ha); thus, the nutritional requirements of black poplar are about two times greater than those of loblolly pine, both when the basis of comparison is total accumulation as shown above and when it is tons of dry matter/kg of nutrient:

Species	Total dry matter (tons)/total nutrients (kg)
Black poplar	0.091
Loblolly pine	0.219

Another difference between poplar and pine is the considerably higher nutrient content of poplar bark, although this component is about the same proportion(12 percent) of the stand biomass of both species. This difference has practical significance when one considers that at age 16, the stem or harvestable component of poplar stands contains about two-thirds of the accumulated nutrients, while stems of loblolly pine contain only about half of the accumulated nutrients. Of these quantities, the bark of each species contains the following percentages of stem nutrients:

Species	Nutrients in bark				
	N	P	K	Ca	Mg
	Percent				
Black poplar	50	37	36	63	40
Loblolly pine	31	28	27	34	22

Since conservation of nutrients is important for future intensive management of these stands and plantations, debarking and distribution of bark on the site would be a practical way to reduce the nutrient drain associated with harvesting.

CONCLUSION

The patterns of dry matter and nutrient accumulation of natural stands of black poplar are strongly modified by plantation culture. The techniques employed in the closely spaced thinned plantations of the Lower Mississippi Valley capitalize on the early developmental potential of poplars; whereas, the wide initial spacing without thinning used in the Po Valley sacrifices early growth potential in favor of improved development of individual trees in later years. Thus, close initial spacing and thinnings result in efficient site utilization during the first decade; a wide initial spacing does not achieve comparable site utilization until late in the second decade.

The nutritional requirements of black poplar per unit of dry matter produced are relatively high and are not influenced by mode of culture. When poplar plantations and stands are compared to loblolly pine plantations at age 16, the nutritional requirements of poplar are twice as great. In particular, poplars require large quantities of the bases K, Ca, and Mg, a fact that explains why poplars grow best on soils high in available bases. Thus, in addition to selecting soils with good physical properties, land managers should seek soils high in available bases.

Of practical importance for poplar is the high concentration of nutrients in the bark. Since nutrient conservation is of potential importance in maintaining site productivity, debarking on the site during harvesting may be a practical means of reducing nutrient drain associated with harvesting.

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