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RESPONSE OF AIGEIROS POPLARS TO SOIL AMELIORATION

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Abstract.--This paper briefly reviews some of the literature available on fertilization, irrigation, and soil physical improvement for eastern cottonwood, its hybrids, and related species. Included are references from Europe, the United States, and Asia.

Additional keywords: *Populus deltoides*, black poplars, fertilization, irrigation, soil physical improvement.

Poplars grow rapidly and respond well to soil amelioration. This paper briefly reviews some of the world literature available on site amelioration for *Populus deltoides* Bartr., its hybrids, and related poplars.

FERTILIZATION

Europe

Europe's relatively small wood-producing areas necessitate increased forest productivity from the land available. Mayer-Krapoll (1956) made general observations about the nutrient regimes used over a variety of environmental conditions. Other papers have been published that give recommendations for fertilization in Europe (FAO 1958, Baule and Fricker 1970). Most authors stress the importance of nitrogen.

Italy.--In Italy, favorable results have been obtained with both nitrogen and complete fertilizer treatments in field plantings and in nurseries. Lavezzini (1957) recommended that NPK in combination with manure be placed in the planting hole and that NPK then be applied annually in bands around the tree.

In nurseries of improved planting stock, Giulimondi (1970) recommended an application of NPK in the spring to meet the extra nutrient requirements at the start of the growing season. Giulimondi (1972a, 1972b) also found that heavy applications of N were not necessary if leguminous plants (lucerne) were included in nursery rotations and if organic manures were added periodically. Liani (1967a, 1967b, 1971) reported height and weight responses of improved nursery stock to sulfur, to foliar applications of P, and to NPK.

Frison (1974) found that fertilization with N or NPK was beneficial only on poor soils that have been impoverished by agronomic cropping. In

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cases where fertilization may be necessary, Giulimondi and Duranti (1974) suggested that N and P be applied early in the season, while K, Ca, and Mg, if needed, be delayed until midsummer.

France.--In the nursery, Hitier (1947) increased the number of usable plants by a basic application of slag and KCl plus N immediately before planting. In the field, Hitier obtained increased height and diameter at age 13 after applying NPK in the second and third growing seasons. Hitier therefore concluded that fertilization was economically feasible in both the nursery and the field.

According to Chardenon (1957), nurseries on humus-rich alluvial soils should be treated with farmyard manure in the fall and with P and K during winter. On loams, he recommended increased manure applications but only half the P and K rates. When the trees are outplanted, Chardenon recommended that N be added and that lime be applied to acid soils. Chardenon (1960) later found that P improved growth and that N produced a slight improvement but that K was of no benefit on drained marsh. On slightly acid fine sand, additions of K and Ca to the planting hole gave best growth.

Leroy (1969) found that placing NPK in the planting hole increased growth rate, decreased losses from disease, and promoted root growth on fertile, loamy, calcareous gleys.

Barnéoud and Bonduelle (1971) reported that NP fertilizer was always effective but that the reaction to K, Ca, and Mg was variable and unpredictable. After further testing, Barnéoud (1974) suggested that repeated surface applications of NPK would be economical in northern France. In the Paris basin, Garbaye and Leroy (1974) reported that surface application of N for 3 successive years after planting produced a 43 percent increase in diameter.

Germany.--Günther (1957) found increased height growth with increasing amounts of NPK plus Mg and Ca for 1-year-old plants growing in a rather infertile, neutral sandy loam soil. Hausser and Troeger (1964) reported improved height, diameter, and root development after three applications of Ca given with N. N alone was better than either Ca or P alone, which depressed growth slightly.

Fritzsche and Kemmer (1961) obtained increased diameter, height, and dry weight by adding NPK plus Ca. Best growth resulted from split applications of NPK--part early in the season and the remainder 8 weeks later, or PK added early followed 4 weeks later by N.

Borsdorf (1965) reported gains in tree height and wood fresh weight after adding NPK as well as individual nutrients to a poor sandy soil. Although fertilization decreased wood density, the reduction was offset by added weight.

Netherlands.--Most European researchers have reported no response of poplars to added K; however, van der Meiden (1964) found increases in height, diameter, and volume 4 years after K treatment plus N on polder soils. Van der Meiden (1959) also demonstrated an inverse relationship between foliar K and rust attack. According to Schönnamsgruber (1965), fertilization with K doubled foliar K content and increased average height.

Liekens (1962) showed benefits from adding K to poplar plantations but he also demonstrated a diameter increase from N and reported best growth from adding NPK. Later, van der Meiden (1965) asserted that K should always be applied with N.

England.--Jobling (1960) increased tree height by adding P and K to the planting pit and N as a top dressing. Jobling (1963) also suggested improving early growth by applying NPK in the planting hole or PK alone followed later by a surface application of N.

Bulgaria.--Fertilization and fertilizer x water interactions are being studied in Bulgaria. Denev (1974a) obtained greater responses to fertilization in river sand than in fine-textured alluvial soil. After observing movement of N, P, and K from older leaves to meristems in late July, Denev (1975) suggested applying soluble N and K in plantations in June or July. Denev (1974b) also found that NPK plus irrigation gave the best growth response, though NPK was only slightly better than NP. Because fertilizing without irrigation had little effect on growth, he recommended NP plus irrigation in the second half of the growing season.

Other European Countries.--In Hungary, Pántos and Pántos (1971) found that NPK was the most effective fertilizer combination. Working with solution culture, Pántos (1972) found a rich supply of NP to be critical for root development and survival. In the Vistula Valley in Poland, NPK increased tree diameters; fallowing and lupins had no effect on growth (Milewski and Zajączkowski 1971). In Czechoslovakia, Mráz (1965) emphasized adding soil nitrates during May and June. In Sweden, Karlberg (1954) found that 1-year-old poplar seedlings on a sandy soil responded slightly to PK but vigorously to NPK, another indication of the importance of N for poplars.

Asia

Although poplar culture is receiving increasing attention in many parts of Asia, there is little fertilization research. In India, for example, most fertilization consists of applying manure to agricultural crops planted between the rows of trees (Asthana 1971). In Pakistan, Sheikh obtained diameter increases after adding urea to individual trees (see present publication).

United States

During the mid-1940's, the Southern Forest Experiment Station tested fertilizers in plantations in the Mississippi River floodplain (USDA Forest Service 1947). Applying N seemed a satisfactory and inexpensive substitute for hoeing in 1947, but later, fertilization appeared to decrease survival. It was not until the 1960's that renewed interest in the fertilization of poplars was expressed in the United States. In Iowa, Brendemuehl (1957) found that adding N and Ca increased growth markedly. Nitrogen alone depressed growth as did K. There was a positive relationship between site index and foliar N.

Aird (1962) concluded that a deep application of NPK should be applied at planting; broadcasting did not allow trees to overcome competing vegetation. He suggested that tillage or herbicide treatments were necessary for effective fertilization.

Based on his observations in Europe, Schreiner (1959) recommended fertilizing at planting time and liming to increase soil pH to 6.0-6.5.

Bonner and Broadfoot (1967) showed that cottonwood grew best in the greenhouse with nutrient solutions containing 100, 75, and 100 ppm N, P, and K, respectively. In greenhouse tests, Blackmon and Broadfoot (1969) obtained greater growth after adding N to Bibb--an infertile, acid, alluvial soil--than to Commerce silt loam. Adding lime plus NPK to the acid soil achieved large growth increases.

Blackmon and White (1972) obtained a 200 percent growth increase for trees fertilized with N. There was no response to P alone nor was there any advantage to adding P with N. A foliar level of 2 percent appears critical. Responses to N fertilization are most likely to occur when the soil contains less than 1,100 kg/ha total N (Blackmon, unpublished data).

Trees on a poorly drained slackwater soil in the Mississippi River floodplain have shown only slight responses to N fertilization (Blackmon, unpublished data). When applied at age 2, fertilization was ineffective; at age 3 there was a slight response; the largest response occurred at age 4. This is probably the result of increasing tree-to-tree competition as the stand ages.

Crown Zellerbach (1971b), however, found that diameter growth of trees fertilized with N was more than doubled. In other experiments with N, responses varied from 40 percent to almost 500 percent according to site condition and history (Crown Zellerbach 1971a, 1972a, 1972b, 1972c, 1973a, 1973b). In studies of fertilization in combination with cultivation, Crown Zellerbach (1972a) obtained no significant growth differences between trees receiving 3 years of cultivation plus N fertilization and those receiving only cultivation for 3 years. Previously, Crown Zellerbach (1971a) had shown that continued cultivation during the second growing season caused large increases in foliar N levels. These results are similar to those of Aird (1962). Both studies strongly indicate that cultivation helps poplars by improving N nutrition.

In an economic analysis of the benefits of N fertilization, Crown Zellerbach (1974) found that increased growth from fertilization almost offset the cost of treatment during the first year. By the end of the second growing season, the value of the growth caused by fertilization was almost double the cost of the operation (Crown Zellerbach 1975).

In Alabama, Martin and Carter (1967) increased cutting yield by applying NPK plus additional N in a nursery. In other Alabama studies, White (1969) found a strong relationship between height growth and extractable K, a result similar to that found in the Netherlands (van der Meiden 1964, Schönnamsgruber 1965). Crown Zellerbach (1976) applied K in cottonwood plantations but obtained no response.

When Carter and White (1971) applied N, NPK, and lime at planting time on a Norfolk soil, they obtained a large but short-lived response in height growth. They recommended that neither strongly acid soils (below pH 5.0) nor those low in exchangeable Ca (less than 1,000 ppm) be planted unless a heavy application of lime is included. Kaszkurewicz (1973) concluded that 3,400 - 3,800 ppm Ca is optimum. However, applying 6.7 metric tons of lime per hectare to strongly acid (pH 4.0) silty clay soil in the Coastal Plain increased heights by only 17 percent (Blackmon, unpublished data).

On Coastal Plain alluvial sites in Texas, Capel and Coffman (1966) recommended applying a starter fertilizer (N and P) in the subsoil trench. Working in the same region on soils of the Brazos River floodplain, Huebinger (1969) found that dry matter of cottonwood was increased 52 percent by applying N and P in bands around the tree.

When Curlin (1967) applied N to improved cottonwood on moderately drained soils in Tennessee, mean diameter and height of the clonal population were more than doubled and volume growth was increased nine times, although specific gravity of most clones decreased with fertilization. However, in Illinois, Bhagwat (1967) reported that NPK increased wood specific gravity and fiber length as well as height and diameter growth. He concluded that fertilization did not lower wood quality but in fact improved it.

Foliar applications of NPK in well-stocked stands of poor vigor increased height but not DBH (Crown Zellerbach 1971c). Foliar fertilization is more common in horticulture than forestry, but a large number of preparations are available (Lyle 1972) for testing on poplars.

<u>Summary (Fertilization)</u>

In spite of the wide range in methodology and results reported on poplar fertilization throughout the world, certain trends are evident:

(1) Nitrogen is of almost universal importance.
(2) Poplars on strongly acid soils require large doses of lime.
(3) Poplar responses to fertilizer, particularly for N, are usually of short duration.
(4) Foliar N deficiency level appears to be about 2 percent.
(5) Fertilization appears economically feasible only on poor sites--particularly those impoverished by agricultural cropping. A tradeoff between fertilization and cultivation may be possible.
(6) The influence of fertilization on wood properties is not known but appears related to genotype.
(7) Fertilization appears to decrease the incidence of insects and disease, but results are not conclusive.

(8) Fertilization in most European countries consists of an application of NPK or PK to individual trees at planting time, followed by a surface application of N later during the growing season. Subsequent fertilization is done when necessary.
(9) In many areas of Europe, K applied alone depresses growth, although positive responses have been observed in Holland.
(10) In the United States, fertilization is normally delayed until the stand is established.
(11) In the United States, fertilizers are usually applied by surface broadcasting, whereas in other countries, subsurface placement and banding on the surface are common.

IRRIGATION

During a severe mid-1950 drought in the United States, widespread dieback and mortality demonstrated the importance of soil water for hardwoods, including cottonwood. Impounding water in stands from February to July to depths up to 90 cm for 4 successive years increased cottonwood radial growth by 90 percent (Broadfoot 1967).

Tree volumes at Stoneville were increased both by sprinkler irrigation of individual trees and by flood irrigation to a depth of 25-50 mm (unpublished data). Volumes on the plots watered with sprinklers increased by 59 percent, compared to 15-40 percent for trees on flooded areas. Maximum response occurred with late summer irrigation; Schmidt (1975) also showed that water uptake reached a peak in July and August. In both experiments, growth responses to added water were most apparent in dry years.

In countries with lower rainfall than in the southern United States, irrigation might have greater application. In Israel, for example, Rawitz, Karschon, and Mitrani (1966) obtained a large response by adding water to plantations but concluded that poplar probably could not compete with other irrigated crops for limited water and land. In India, Asthana (1971) recommended irrigation weekly during the first season and biweekly or less thereafter. In Bulgaria, which has higher rainfall, growth was improved by applying 250 to 400 mm of additional water per growing season (Dimitrov and Denev 1973). In Pakistan, a low rainfall area, Sheikh (1972) recommended applying 18 liters of water to each tree at planting, then irrigating frequently in spring and summer either in trenches or by flooding.

Other methods of irrigation being attempted include ditch or furrow irrigation for plantations in Turkey (Jaime Fanlo and Chardenon 1971) and Pakistan (Sheikh 1972) and flood irrigation in the United States. In Italy, Liani (1974) found the drip system superior to sprinkler irrigation.

Brendemuehl (1957) obtained best results for cottonwood in the greenhouse by maintaining moisture at the moisture equivalent level on soils with a low bulk density and at a level lower than the moisture equivalent on soils with high bulk density. Papadopol (1969) found the optimum moisture level to be about 70 percent of field capacity. According to Fritzsche (1967), the optimum is 100 percent of field capacity in a coarse-textured soil. Naĭdenova (1975) found best growth at 70-85 percent of maximum water-holding capacity, a finding similar to that of Ganchev and Iovov (1972). Broadfoot states that in well-drained soils, best cottonwood growth is obtained when soil moisture is maintained at or near field maximum moisture content (personal communication).

Bonner (1967) found that terminal growth of cottonwood stopped when leaf water deficits reached 4 percent in sandy loam and 5 percent in clay, indicating a sensitive control of water loss. Regehr, Bazzaz, and Boggess (1975) observed maximum photosynthesis when leaf water potentials were -3 to -8 bar; photosynthesis fell to zero at -11 bar.

In various parts of the world, poplars have been irrigated with industrial and municipal effluents. In France, Koch (1958) reported increased yields from a poplar plantation irrigated with city and factory wastes since 1929. When Dragun (1964) applied purified town effluent to a plantation, volumes of irrigated trees were almost double those of controls. Wood density was slightly reduced in irrigated trees, but cellulose content remained constant. In the United States, Rudolph and Dils (1955) found that irrigating cottonwood with cannery waste water increased first-year heights.

Summary (Irrigation)

Success with irrigation in poplar culture varies with average rainfall, availability of irrigation water, costs of applying water, and expected return from the product being grown. In arid regions such as southern Pakistan and Israel, poplar culture may ultimately be sacrificed to agricultural crops because of limited water supply.

In high rainfall areas such as the southern United States, irrigation of cottonwood seems feasible only during periods of extended drought, since growth response during periods of normal rainfall have been insufficient to justify irrigation.

Where irrigation is feasible, maintaining the water supply at 80-90 percent of maximum water-holding capacity appears optimum. The amount of water needed depends on such factors as rainfall patterns, soil texture, porosity, tree spacing, and tree age. Older trees appear to respond more than young ones, probably because of increased competition for moisture.

SOIL PHYSICAL TREATMENT

Physical condition as determined by soil structure is the key to soil excellence for production of poplars and other hardwoods (Broadfoot, Blackmon, and Baker 1972). Although sites with medium-textured alluvial soils are usually highly productive in their virgin condition, they are susceptible to physical damage. Compaction, for example, produces poor aeration, slow water infiltration, and poor internal drainage, all of which lead to suboptimum tree growth. Broadfoot and Bonner (1966) reported that best cottonwood growth occurred when bulk density was 1.4; root and shoot development were restricted at a bulk density of 1.6, which is equivalent to a total porosity of 38 percent. Hidding and van den Berg (1961) found that root growth of several agricultural crops is inhibited if total pore volume falls below 40 percent.

Brendemuehl (1957) stated that growth significantly decreased as bulk density increased from 1.08 to 1.40, a somewhat lower optimum than was reported by Broadfoot and Bonner (1966).

Deep plowing has been used in several parts of the world to improve soil physical properties and poplar growth. In Italy, Giulimondi (1968) obtained best growth after plowing to 50-55 cm, and in the Danube delta Clonaru (1968) achieved excellent poplar growth after drainage and plowing to a depth of 40 cm. In Russia, Erusalimskij (1969) attained improved poplar growth by plowing to 40 cm. In the United States, however, Baker and Blackmon (1973) found no growth response from plowing to the same depth before planting cottonwood on an old field in the Mississippi River floodplain. In Pakistan, deep plowing is used for temporary improvement of the very poor structure of saline soils (Sheikh 1974). In the United States, subsoiling in conjunction with planting improves soil structure but the benefits are probably temporary. In agriculture, deep plowing appears superior to subsoil chiseling (Kaddah 1976).

Summer fallowing (disking four times before planting) improved survival and height growth (Baker and Blackmon 1973); cover cropping alone or in combination with fallowing was not effective. In Poland, Milewski and Zajączkowski (1971) did not improve growth by clear fallowing and seeding _Lupinus polyphyllus_ between rows in a 7-year-old poplar plantation. In contrast, Hejmanowski (1974) obtained positive results after bare fallowing.

Summary (Soil Physical Treatment)

Plowing to a depth of 40-50 cm improves soil physical properties on some sites. Because the energy requirements of deep plowing are high, the existence of soil compaction and pans should be verified before the method is employed. Deep plowing would probably improve soils with a bulk density of 1.5 or greater. Summer fallowing is beneficial on many sites--particularly those badly infested with herbaceous vegetation and those in areas where soil moisture conservation is critical.

CONCLUSION

Although soil improvement is often essential, some sites--virgin alluvial ones, for example--require no amelioration. On other sites, such as those that have been cropped by a system of exploitive agriculture, fertilization, deep plowing, cover cropping, or fallowing may be required. Irrigation is essential in low rainfall areas and may be beneficial during dry periods in temperate regions.

Soil improvement will probably be required if it becomes necessary to plant on marginal sites to satisfy the demand for poplar fiber or if soil fertility deteriorates with successive rotations. As the world's supply of fossil fuel diminishes, maximum wood production will be extremely important, and soil management practices hitherto thought impractical might become routine.

In the immediate future, we might attempt to achieve moderate increases in growth on medium to good sites, which would probably result in more wood than large increases on poor sites. At present, proper soil management, good silviculture, protection from insects and diseases, and genetic improvement make increased poplar yields attainable and practicable.

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