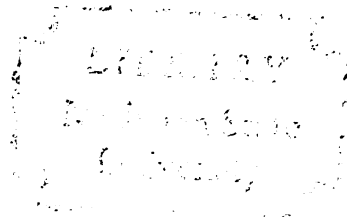


GROWTH, CANKER SUSCEPTIBILITY, AND
ROOTING OF POPULUS DELTOIDES
AND OTHER POPULUS CLONES
IN SOUTHERN MICHIGAN

Thesis for the Degree of M. S.
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ABSTRACT

GROWTH, CANKER SUSCEPTIBILITY, AND ROOTING OF POPULUS DELTOIDES AND OTHER POPULUS CLONES IN SOUTHERN MICHIGAN

By

Richard Paul Kelly

A provenance test involving 166 clones of 85 families of P. deltoides, 20 clones of two families of P. nigra, and four Populus hybrid clones was established at Michigan State University in 1965. Unrooted cuttings were taken from the original plantation and used to establish four replications between 1968 and 1970. Height growth and diameter growth were measured in 1974. Survival, leaf flushing date, and stem canker occurrence were scored in 1975. Rooting ability of selected Populus families and clones were evaluated under controlled environment and nursery conditions.

Clones from Minnesota and Ohio stands had the largest average height and diameter of all native cottonwood clones in the provenance plantation. P. nigra and Populus hybrid clones generally exceeded the P. deltoides clones in height and diameter, but were also very susceptible to stem canker. Clones of P. deltoides originating from prairie

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and southern stands had lower rates of survival and lower resistance of stem canker when compared to the clones from more northerly and easterly stands.

Leaf flushing date was found to be under fairly strong genetic control and not greatly influenced by the effects of microsite. Trees from northern latitudes were the earliest to break bud while those from more southern latitudes took longer to begin growth.

Analysis of variance for all traits revealed significant differences between stands, families within stand, and clones within family within stand. Variation between stands was larger than that among families or among clones.

Rooting habit varied between Populus families and clones. A P. nigra family and Populus hybrid clone had the fastest rate of shoot and root elongation and produced more roots of greater total dry weight in a shorter time when compared with the P. deltoides families represented on the rooting studies.

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Richard Paul Kelly

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CHAPTER I

GENERAL INTRODUCTION

Eastern cottonwood (Populus deltoides var. deltoides Bartr.) is one of the largest and most widespread tree species in the eastern United States. Cottonwood's rapid growth, reputed to be the fastest in North America, ease of vegetative propagation, and favorable wood and fiber qualities have resulted in a long standing interest in it as a timber species (McDonald 1924, Bull and Muntz, 1943). In addition, the ease by which inter- and intra-specific hybridization can be accomplished make it an excellent choice for genetic improvement.

Breeding programs initiated in the early 1960s in the Lower Mississippi River Valley have resulted in the development of improved cottonwood clones now in commercial production (Johnson, 1972). In the North Central Region cottonwood and related hybrid poplars have not, as yet, been planted widely enough to justify large scale breeding programs. But eastern cottonwood has shown good potential for practical genetic improvement, i.e., it possesses a high

probability of producing improved material within a reasonable time (Mohn, 1973).

Populus sp. have also been identified for use in high yield intensive management systems (Dickmann, 1975). Crist and Dawson (1975) found that two Populus clones grown for short rotations at dense spacings produced extremely high yields of material of acceptable quality. In the North Central Region commercial application of intensive poplar culture is possible and probably will be centered on some of the four million acres of excellent to good quality sites presently available for planting in this region (Dawson and Pitcher, 1970).

This thesis is presented in two parts. The first summarizes the results of a provenance test of eastern cottonwood established by Michigan State University in 1965 as part of a cooperative cottonwood improvement program of the Agricultural Experiment Stations of the North Central Region of the United States (formerly Project NC-51, now NC-99). A previous paper on this study has been published by Ying (1974). The second part of the thesis discusses a study of the variation in rooting ability among various Populus sources selected from the Michigan State University provenance plantation.

CHAPTER II

REVIEW OF LITERATURE

Systematics

The genus Populus consists of about 35 species divided into five sections: Leuce (aspens and white poplars), Tacamahaca (balsam poplars), Aigeiros (cottonwoods), Leucoides, and Turanca. The natural distribution of the poplars is limited to the northern hemisphere, where they range from the equator to the northern tree line. Ten species are currently recognized as native to the United States, but only five occur in sufficient quantity to be commercially important (Little, 1953).

P. deltoides is in the section Aigeiros and is its most important representative in North America. Considerable confusion exists in the nomenclature of this species because of its wide distribution and hybridization and introgression of eastern cottonwood with other native poplar species. Plains cottonwood (P. deltoides var. occidentalis Rydb.) resembles eastern cottonwood in general appearance and confusion exists in differentiating between the two (Fowell, 1965). Some authors do not recognize a

plains variety and show eastern cottonwood as ranging to the Rocky Mountains. Others recognize plains cottonwood as a separate species, P. sargentii Dode. In European literature the collective species P. deltoides is divided into three subspecies: "angulata Ait.," a southern variety, "monilifera Henry," a northern variety, and "missouriensis Henry," an intermediate type. In this paper plains cottonwood will be treated as a variety of P. deltoides. Ying (1974) and FAO (1958) present more complete discussions of the taxonomy of eastern cottonwood and other poplars.

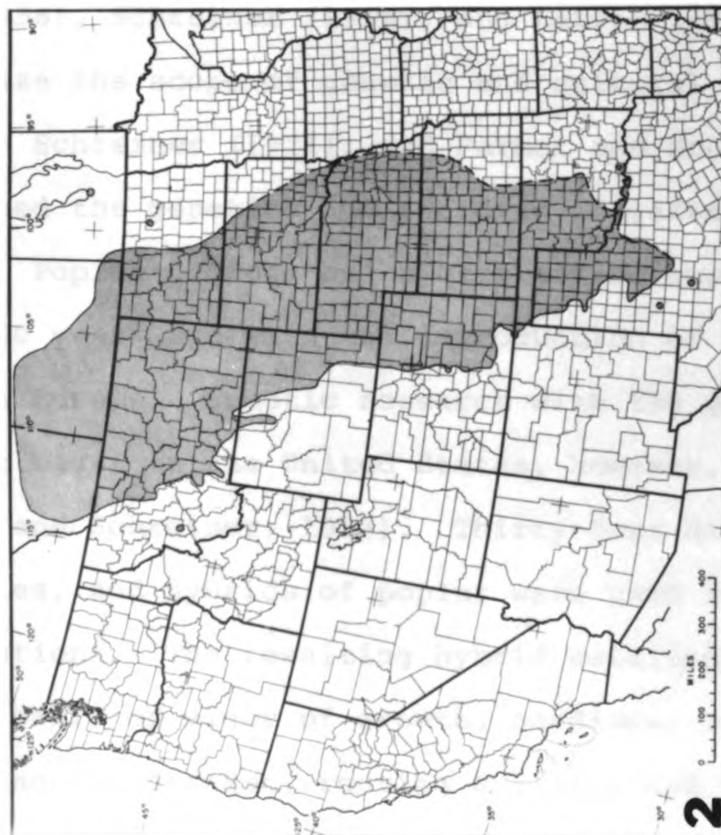
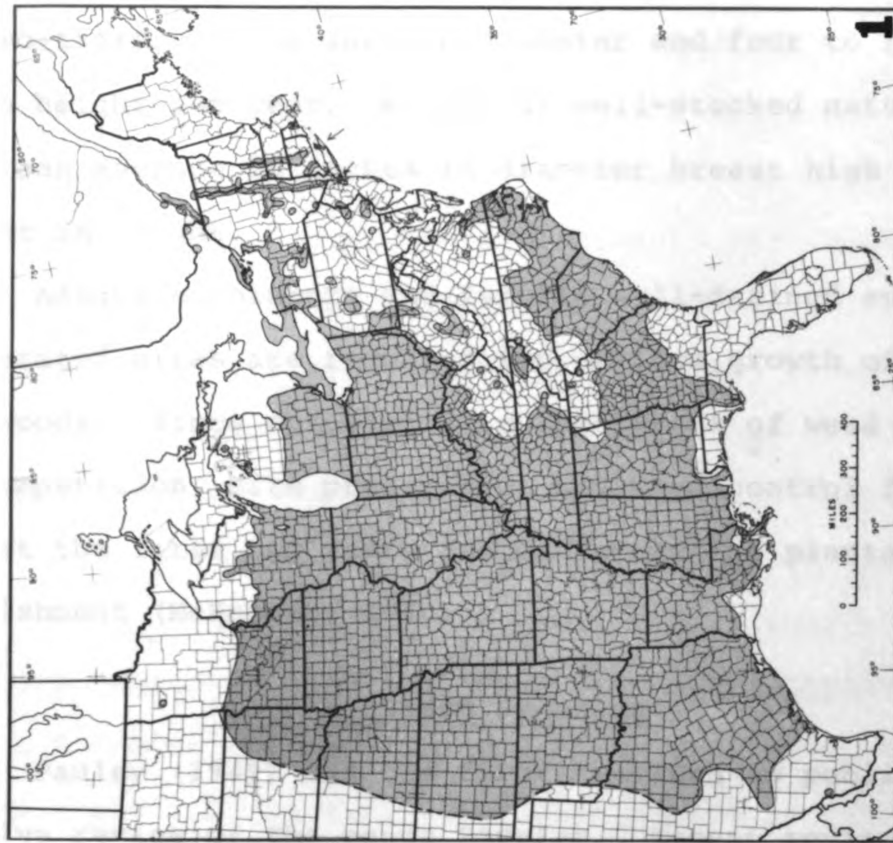
Distribution-Habitat

P. deltoides covers a wide range from the central Great Plains to the southern Atlantic coast and from the Lake States to the Gulf of Mexico (Figure 1). Eastern cottonwood, however, is not common in the extreme Northeast or Appalachian region (Little, 1971). The western limit of the range of eastern cottonwood is not well-defined because in this portion of its range it overlaps with that of plains cottonwood (Figure 2).

Eastern cottonwood is very intolerant and occurs most often in even-aged pure stands or as a dominant in a mixture with other hardwood species. Cottonwood will only establish itself on moist bare mineral soil and is commonly found growing naturally on alluvial soils along river banks or on bottom-land sites (Fowells, 1965). On the best sites in the Mississippi Valley unmanaged cottonwood trees often

Figure 1. Natural range of P. deltoides var. deltoides
Bartr. (from Fowells, 1965).

Figure 2. Natural range of P. deltoides var.
occidentalis Rydb. (from Fowells, 1965).



grow two-thirds to one inch in diameter and four to five feet in height per year. At age 35 well-stocked natural stands can average 20 inches in diameter breast high and 120 feet in height.

Adequate moisture and fertile well-drained and well-aerated sites are required for optimum growth of cottonwoods. Since cottonwood is intolerant of weed or vine competition, site preparation and weed control for at least the first two years are mandatory for plantation establishment (McKnight, 1970).

Genetics and Breeding

Pauley (1949) was the first American to publish an extensive review of the genus Populus. Recent reviews by FAO (1958), Schreiner (1959), and Larsen (1970) also summarize the scope of genetic and cultural work with this genus. Schreiner (1971), and Farmer and Mohn (1970) have discussed the genetics and breeding of eastern cottonwood.

Poplar culture and hybridization experience began some 250 years ago with the introduction of American cottonwood in Europe. Genetic research with the genus Populus did not begin in the United States, however, until 1924 (Stout and Schreiner, 1933). Thirty-four different species, varieties, and hybrids of poplar were used in 99 cross combinations. The resulting hybrid seedlings were selected on the basis of vigor of growth, hardiness in Maine, resistance to disease, rooting ability, and habit of growth.

Promising hybrids were and continued to be field tested in various locations. Results of these field tests are variable and difficult to interpret because the hybrids have not been planted extensively enough to obtain conclusive information on their performance. Bagley (1973) reported that several of the hybrids exhibited good growth on sites in Nebraska. However, not all hybrids were high in vigor and performance on all sites and he suggested continued research to find clones best adapted to specific sites. Maisenhelder (1970) found that native selections of eastern cottonwood out-performed the hybrid poplars in growth and insect and disease resistance when growing on southern sites. Jones (1973) and Funk (1960) both found that hybrid poplar had moderate to good survival and growth when planted on acid strip mine spoils in the Northeast.

Mohn (1973) recommends the use of hybrids clones in areas where their superior performance has been verified. But in areas where results of tests have been negative or inconclusive selection from local populations may provide the best source of planting stock. In a Nebraska provenance test Ying (1974) found that eastern cottonwood trees from Missouri outgrew all others, including those from Nebraska. These results indicate that selection from nonlocal populations can also result in improved growth rates.

In the 1950s breeding programs for P. deltoides were initiated in the Lower Mississippi Valley at the U.S. Forest Service Southern Hardwoods Laboratory, Stoneville,

Mississippi. The goal of these programs was development of planting stock with superior genetic potential for economically important traits. Encouraging early results led to expanded breeding programs in the 1960s (Johnson, 1972). After five years growth, 14 clones were selected as superior. These clones exceeded controls by 13-20 percent in diameter and 10 percent in height and have now been certified and released for propagation and distribution (Land, 1974).

Pauley and Perry (1954) investigated geographic variability in the genus Populus. They found that adaption of Populus species to various habitats differing in length of the frost free period is affected by a genetic mechanism which controls the duration of their seasonal growth. Seedlings from latitudes 30° to 38° N had poor survival due to winter kill in Minnesota, but some surviving southern clones did exhibit better juvenile growth than local sources (Mohn and Pauley, 1969).

The Texas Forest Service established clonal tests of local poplar selections and other material from Eastern United States. Results from East Texas show that local clones were superior in growth, volume, and dry weight production (Wossener, 1970). Hybrid poplar clones, however, were found to be more resistant to cottonwood twig borer (Gypsonoma halmbachiana Keaf.) than were local clones (Wossener and Payne, 1971).

Farmer (1970) collected open pollinated seed from natural stands of eastern cottonwood along the Mississippi River. He found that^a variation in height between families was statistically significant but that field selection of parents for growth was completely ineffective in terms of juvenile progeny performance, i.e., mean heights and diameters of progeny from phenotypically superior parents and randomly selected parents were identical and ranges of family means for both groups were also similar. Familial variation for foliation date, rust resistance, and specific gravity was found to be much greater and family selection for these traits would be very effective.

Ying (1974) studied growth, survival, injury, and morphological and phenological traits in a provenance test of P. deltoides and found significant differences among geographic regions. Variation within families was found to be larger than the variation among families for most traits.

Methods of breeding P. deltoides have been summarized by several authors (Schreiner, 1970; Mohn, 1973; Farmer and Mohn, 1970). Mohn (1973) has recommended a series of clonal tests aimed at evaluation and selection of clones from local populations. When adequate numbers of local cottonwood sources are tested new populations that have a high occurrence of favorable genotypes could then be located through provenance tests.

Schreiner (1970) emphasized that the first step for genetic improvement of P. deltoides should be selection of

plus trees from all regions of its natural range. Maximum genetic gain could then be obtained by the use of plus tree clonal propagation, half sib propagation, and intra- and inter-specific crosses. Selection and clonal testing of plus trees is the simplest improvement procedure and could provide material for commercial planting in three to four years. Propagation and evaluation of the half sibs of plus trees would provide provenance information as well as knowledge of heritability. Controlled intra- and inter-specific crosses would provide for maintenance of the broadest possible genetic base.

Farmer and Mohn (1970) conclude that although some gains have been made in field selection of parents the expense of family separation and evaluation could probably be avoided without great loss. Mass selection in natural populations and then thorough testing of the seedlings as clones would result in the greatest genetic gain.

All authors have stressed the necessity of testing a large number of clones in order to maintain a high selection differential and adequate genetic diversity. According to Schreiner (1972) the most important criteria for selection of superior clones are (1) rooting ability, (2) rapid growth (volume production), and (3) sufficient pest resistance.

Rooting Ability

Differences among clones in rapidity of initial root development on hardwood cuttings can affect plant

establishment and evaluation of early growth. Wilcox and Farmer (1968) found that first year growth of cottonwood was probably a reflection of the initial root habit or other unknown factors which affect establishment, with little competition between cuttings. Second year growth better reflects clone vigor while under stand conditions following establishment. Ying (1974) found that rooting ability varied from clone to clone and that initial growth rate of the clone is related to its ability to establish a strong root system immediately after planting. After the unrooted cutting became established, other hereditary characteristics governing rate of growth became dominant factors.

Cunningham (1953) found considerable variation in rooting ability among clones from natural stands of eastern cottonwood and hybrid sources. Bloomberg (1963, 1959) found significant differences in the number and length of roots produced on cottonwood cuttings taken from different quarters of a stem. Cuttings taken from the basal portion of one-year old stems produced more rootlets, suggesting that differences in food reserves along the length of the stem may be a controlling factor. Farmer (1966) determined that date of collection can also influence root production. Cuttings collected in February produced more roots than those collected in December or March. Presumably, cuttings taken in December have not yet fully overcome the requirements for breaking dormancy, so apical growth and rooting

ability are slow. Cuttings taken in March tend to foliate before rooting thus creating a nutrient and moisture stress which probably lead to reduced rooting.

Allen (1956) showed that as the age of the tree from which cutting material is taken increases, survival of unrooted cuttings decreases. Longer, deep planted cuttings survive better, probably because of increased food reserves and closeness to available moisture. Diameter of cutting was found not to influence survival or number of roots.

Wilcox and Farmer (1968) found that variations in root development of cottonwood clones was under genetic control and related to foliation date, i.e., clones that flushed early started root growth early. Controlled crosses of F_1 poplar individuals possessing high rooting capacity to native unselected individuals produced progeny that all had high rooting capacity (Johnson, 1946). These results are not conclusive; but, they do suggest that rooting capacity may be transmitted to the progeny as a dominant character.

Rapid Growth

P. deltoides is an extremely heterogeneous species. Potential for improvement of growth rate and wood properties through selection and breeding, therefore, is great. But creation of genetically superior fast growing cottonwood

trees will not result in maximum gain unless proper cultural methods are also employed.

McKnight (1970) has outlined in detail a system for planting cottonwood cuttings that has proven highly successful in the fertile river bottoms of the South. He stresses that high yields can only be obtained through a combination of careful site selection, thorough site preparation, weed control during the first year, and protection from insects and grazing animals. Early and frequent thinnings may also be important, depending on the goals of management. On good sites cottonwood grown in short pulpwood rotations at a spacing of 10 by 10 feet can yield 45.7 cords per acre at age 12.

Schreiner (1970) has described an intensive culture system for use in the Northeast United States. Superior species and hybrids would be grown in short "mini rotations," i.e., fiber rotations of two to five years, boltwood rotations of six to 15 years, and sawlog and veneer rotations of 15 to 30 years. Fiber production from hybrid poplars grown at a 1 by 4 foot spacing for four years ranged from 2.2 to 8.2 cords per acre. At a 6 by 6 foot spacing hybrid poplars yielded 10 cords per acre of boltwood thinnings between the eighth and tenth years, and a final harvest of 30 cords per acre at 15 years.

In the North Central Region maximum growth of cottonwood species can only be achieved on the inherently fertile sites which are well drained, well aerated, and

adequately supplied with moisture throughout the growing season (Dickmann, 1975). As in the South and Northeast, a high level of silviculture, especially control of competing vegetation, will be necessary to bring out the yield potential of cottonwood.

Pathogen Resistance

Hepting (1971) discusses many of the common diseases associated with Populus species of North America. One of the most widely known of the poplar cankers is caused by Dothichiza populea. It attacks many hybrid and poplar species, chiefly young planted trees and those in nurseries.

Waterman (1957) gives a detailed account of Dothichiza populea in the United States. Degree of susceptibility to this pathogen was found to vary among clones of poplar species and hybrids.

Leaf Flushing

Wilcox and Farmer (1967) and Ying (1974) both found foliation date to be under fairly strong genetic control. Trees from north and west geographic regions generally broke bud earlier than trees from south and east geographic regions (Ying, 1974). Kaszkuvewicz and Fogg (1967) correlated latitude positively with date of bud break in natural stands of eastern cottonwood, while McMillian (1957) observed a progressive northwest to southeast pattern of leaf flushing in natural stands of eastern cottonwood trees of Nebraska.

CHAPTER III

PROVENANCE TEST

Introduction

In 1964, a cooperative cottonwood improvement program was initiated by Dr. J. J. Jokela of the University of Illinois, as part of a region-wide project of the Agricultural Experiment Stations of the North Central Region (NC-99, formerly NC-51). Open pollinated eastern cottonwood seed was collected from native stands throughout the natural range, and kept separate according to half sib family. Ying (1974) gives details of this collection.

In April, 1965, 1-0 seedlings were distributed to participating experiment stations (Michigan, Nebraska, Illinois, North Dakota, Wisconsin, Kansas, Minnesota, Indiana, Ohio). A total of 756 seedlings of P. deltoides from 127 families and two sources of P. nigra (3824, 3825) were shipped to the Michigan State University Forestry Department for establishment of a provenance plantation. The present study was initiated to summarize the results from this plantation.

The objectives of this study were:

1. To evaluate height growth, diameter growth, and leaf flushing differences among the P. deltoides sources.
2. Compare height growth, diameter growth, and leaf flushing of P. deltoides clones with that of the P. nigra clones and Populus hybrid clones.
3. To evaluate and compare the canker susceptibility of all the Populus sources in the plantation.

Materials and Methods

Cottonwood seedlings were planted in a stool bed at the W. K. Kellogg Forest, Augusta, Michigan. The planting site was a Fox sandy loam with a 5-10 percent east slope, previously in corn for many years. Site preparation for the stool bed included mowing corn stubble and spraying quackgrass with amino-triazole. The seedlings were planted on April 29, 1965, in plots with six seedlings per single open pollinated family. The spacing was 2.4 m. (8 feet) between rows and 1.8 m. (6 feet) between plots. Simazine was applied to the plantation in complete coverage in May, 1965. This single initial replication was used as a stool bed from which unrooted cuttings were obtained to establish further replications in 1968, 1969, and 1970. The stool bed was fertilized in 1967 to assure vigorous growth for cutting material.

In addition to the cottonwood provenance sources, a single Michigan source (P. deltoides of East Lansing origin) and cuttings from four hybrid poplars growing at

Kellogg Forest (H-47 P. 'charkowiensis' X P. 'candina', H-48 P. X euramericana 'erecta', H-96 P. nigra X P. trichocarpa, H-106 P. 'rasumowskyana' X P. 'increassata') were included in all replications. The poplar hybrids were originally obtained from the Dow Chemical Company and are of unknown origin.

Four replications were planted according to the following schedule: one replication in 1968, one replication in 1969, and two replications in 1970. Site preparation each year included plowing and harrowing. Hardwood cuttings used in the establishment of each replication were taken from the stool bed in the previous winter of each year. The 1968 replication was planted adjacent to the original stool bed and the 1969 replication was planted adjacent to the 1968 replication. The site for the two 1970 replications was the former stool bed. Stumps were removed before the cuttings were planted.

Two tree plots were planted with 2.4 m. (8 feet) between rows and 1.8 m. (6 feet) within rows (Figure 4). The Mississippi clones were not planted in the 1970 replications because of their poor survival in the 1968 and 1969 replications.

Measurements of height and diameter at 1.4 m. (4.5 feet) were made in all replications in Fall 1974. Survival, leaf flushing date, and stem canker occurrence were evaluated in Spring 1975. All data were subjected to analysis of variance using plot means as items. Variance

analysis took the form of a nested classification with unequal subclasses. Clones of each half sib family were grouped according to latitude and longitude into 16 stands (Figure 3). Components of variance due to stand, family within stand, and clone within family within stand were estimated by setting the mean squares equal to their expected values and solving for the desired components.

Results and Discussion

Survival

Low rates of survival were generally associated with trees originating from prairie and southern stands (Table 1). Clones from stands in Nebraska, Missouri, Oklahoma, Arkansas, Kansas, and Mississippi all exhibited less than 66 percent survival when growing in a Michigan provenance plantation. Survival of Mississippi clones was the lowest with only 53 percent of the clones surviving the first growing season and only 35 percent of the clones surviving the first winter.

Short growing seasons and low winter temperatures may explain some of the mortality associated with southern clones. Ying (1974) found that 90 percent of the cottonwood clones from south of 33°N latitude were either dead or had repeated diebacks when growing in a Nebraska plantation, while Mohn and Pauley (1969) reported that cottonwood seedlings from 30° to 38° N latitude had poor survival in Minnesota because of winter killing. Low survival of

Figure 3. Sixteen native stands of P. deltoides represented in the Kellogg Forest provenance plantation.

<u>Stand #</u>	<u>Abbreviation</u>	<u>Origin</u>	<u>Mean Latitude</u>	<u>Mean Longitude</u>
1	OKL	Oklahoma	36°05'	97°15'
2	CNEB	Central Nebraska	40°40'	99°20'
3	ENEB	East Nebraska	41°00'	95°50'
4	IND	Indiana	40°25'	86°55'
5	COHIO	Central Ohio	40°35'	80°35'
6	ARK	Arkansas	34°45'	92°15'
7	KAN	Kansas	39°15'	96°30'
8	NCMIS	North Central Mississippi	33°50'	91°00'
9	SMIN	South Minnesota	44°15'	91°55'
10	SCHMIN	South Minnesota	44°40'	91°55'
11	CMIN	Central Minnesota	45°10'	92°40'
12	SOHIO	South Ohio	38°50'	82°00'
13	MO	Missouri	38°55'	92°25'
14	NILL	North Illinois	41°50'	90°10'
15	CMIS	Central Mississippi	33°00'	91°10'
16	MICH	Michigan	42°45'	84°35'

Table 1.--Survival of P. deltoides (by stand) and other poplar origins in the Kellogg Forest provenance plantation.

Source	Mean Latitude	Mean Longitude	# Trees Planted	% Trees Alive	
				End of First Winter ^a	Spring 1975
<u>P. deltoides</u> stands					
CMIN	45°10'	92°40'	54	89	72
SCMIN	44°40'	92°45'	54	96	87
SMIN	44°15'	91°55'	222	89	82
MICH	42°45'	84°35'	44	98	93
NILL	41°50'	90°10'	158	91	73
ENEB	41°00'	95°50'	56	88	61
CNEB	40°40'	99°20'	14	92	14
COHIO	40°35'	80°35'	24	96	96
IND	40°25'	86°55'	64	81	81
KAN	39°15'	96°30'	46	83	50
MO	38°55'	92°25'	176	87	64
SOHIO	38°50'	82°00'	160	74	73
OKL	36°05'	97°15'	16	94	38
ARK	34°45'	92°15'	8	100	63
NCMIS	33°50'	91°00'	64	23	11
CMIS	33°00'	91°10'	24	46	4
Other origins					
3824			96	97	85
3825			64	97	94
H-48			40	90	68
H-106			40	90	70
H-96			42	98	79
H-47			40	98	83

^a1968 and 1969 replications only.

clones from Mississippi, Oklahoma, and Arkansas in the present study indicate that southern origins are probably not adapted to the relatively short Michigan growing season. Southern trees have a tendency to continue growth late into the fall and can be severely injured by the first frost. Low winter temperatures would also contribute to the mortality of the trees from stands of southern origin.

Latitude does not entirely explain the pattern of survival in the provenance plantation. Low rates of survival were associated with clones originating from prairie stands in Nebraska and Kansas, but not with clones from stands of similar latitudes in Ohio and Indiana (Table 1). Environmental adaptation may be the basis for this discrepancy. Eastern cottonwood grows in humid climates over most of its range, except in the western one-third where the climate is subhumid and semiarid. Thornthwaite (1955) calculated a moisture index by comparing the water need at a location with the moisture surplus or deficit. This index indicates that in the western portion of the range of eastern cottonwood a relative moisture deficit develops during the growing season. In this portion of its range cottonwood is restricted to stream and riverbottom sites where a continuous supply of moisture is available. Trees from this region are thus adapted to the moist sites adjacent to the water courses. The provenance plantation at Michigan State University was established on a Fox sandy loam, a stony well drained site not particularly

favorable for poplars. Clones from prairie states apparently were more severely stressed on this arid site and have experienced a lower rate of survival than clones from the more humid climates of the north and east.

Correlation of the survival and height data was significant ($r=.665$). Trees from stands with the highest survival were the fastest growing, while trees from stands with the lowest survival were the slowest growing. This correlation does not imply that the same factor was responsible for both the poor survival and slow growth. Cause of mortality is often complex and can be due to factors which may be difficult to determine. From a practical standpoint this relationship does indicate that clones from stands exhibiting fast growth were probably most tolerant to the Kellogg Forest site and thus survived best.

Survival among the Italian P. nigra and hybrid poplar clones was high. Results from the rooting study, discussed later in this thesis, indicate that P. nigra 3824 and hybrid-48 exhibited good root initiation and growth. This conclusion is further supported by the good survival of these clones in the provenance plantation (Table 1).

Growth

Significant differences in height and diameter between stands, families within stand, and clones within family within stand were found in the provenance plantation

(Table 2, Figures 5, 6). Trees from CMIN, SMIN, and SOHIO stands had the best average height, while those from COHIO, CMIN, and SOHIO stands had the largest average diameters (Table 3). In most cases the height and diameter growth of the P. nigra clones and the hybrid sources exceeded that of the P. deltoides clones (Figure 7).

Table 4 lists the 25 best families and clones ranked according to height. Superiority of the Italian families and hybrid clones is indicated by the fact that six of the top 11 are of these origins. The fastest growing P. deltoides families were from Minnesota stands. Three of the top Minnesota families (174, 192, 193) averaged 11.5 m. (37.7 feet) in height and 14.2 cm. (5.6 inches) in diameter in seven years of growth. The mean height in the plantation was 7.4 m. (24.3 feet) and mean diameter was 8.9 cm. (3.5 inches).

Stem Canker

Tentative identification¹ of the organism causing cankering in the provenance plantation indicates that the pathogen is Dothichiza populea Sacc. & Br. An unidentified wetwood bacterium was also present in association with the canker disease. Differences in canker susceptibility among

¹Tentative identification by culture was performed by John French of the Department of Botany and Plant Pathology, Michigan State University. Positive identification is not possible without reinoculation of the host.

Table 2.--Mean squares and degrees of freedom for height, diameter, leaf flushing, and stem canker.

Source	df	Height	Diameter
Stand	15	1194.182**	3858.186**
Family/Stand	65	333.061**	1011.647*
Clone/Family/Stand	76	178.781**	597.459**
Error	348	101.061	281.140

Source	df	Flushing	Canker
Stand	15	102.458**	10.338**
Family/Stand	57	12.970**	1.795**
Clone/Family/Stand	73	4.598**	.953**
Error	323	.656	.408

*Significant at the .05 level.

**Significant at the .01 level.

Figure 4. General view of the Kellogg Forest provenance plantation.

Figure 5. Fast growing P. deltoides clone of South Minnesota origin (# 172).

Figure 6. Slow growing P. deltoides clone of North Illinois origin (# 289).

Figure 7. Superior growth and good form of hybrid poplar H-96 (P. nigra X P. trichocarpa).



Table 3.--Canker susceptibility, leaf flushing date, height, and diameter of P. deltoides (by stand) and other poplar origins in the Kellogg Forest provenance plantation.

Source	Mean Canker ^a	Flushing ^b	Height ^c (m.)	Diameter ^c (cm.)
<u>P. deltoides</u> stands				
CMIN	0.6	7.5	9.4	11.9
SCMIN	0.7	7.9	8.6	10.2
SMIN	0.6	7.5	8.7	10.4
MICH	0.2	15.0	7.4	10.9
NILL	1.4	8.2	6.2	6.9
ENEB	1.7	7.6	7.8	7.9
CNEB	2.5	10.0	1.6	1.0
COHIO	0.2	10.8	8.5	12.4
IND	0.4	11.2	8.6	10.7
KAN	1.9	5.9	8.3	8.4
MO	1.5	8.1	6.7	7.6
SOHIO	0.2	9.6	8.8	11.9
OKL	2.0	10.8	3.3	3.0
ARK	1.7	11.0	5.4	4.1
NCMIS	2.2	10.0	1.5	1.3
CMIS	3.0	10.0	3.4	3.0
Other origins				
3824	1.8	8.6	12.1	15.7
3825	2.4	8.5	10.4	12.7
H-48	1.6	9.1	10.9	12.2
H-106	1.4	9.8	10.5	11.7
H-96	1.7	10.1	8.9	9.4
H-47	1.8	10.2	8.6	9.1

^aCanker was scored as follows: 0--no canker observed; 1--light infection, no detrimental effects; 2--moderate infection, some open cankers; 3--heavy infection, large cankers present, secondary pathogens causing wood and some mortality.

^bDays after April 30, 1975.

^cHeight and diameter data for the three youngest replications adjusted to the 1968 mean. Adjusted mean = 1968 replication mean + $\frac{\sum \text{deviations per stand}}{\# \text{ plots per stand}}$.

Table 4.--The 25 tallest poplar origins from the Kellogg Forest provenance plantation with corresponding canker rating.

Rank	Illinois #	Origin	Height	Diameter	Mean Canker Rating ^a
			% of Plantation	Mean	
1	3824	Italy	150	158	1.8
2	H-48	hybrid	144	131	1.6
3	192	CMIN	138	147	0.0
4	3825	Italy	136	133	2.4
5	193	CMIN	132	134	0.0
6.5	H-106	hybrid	128	115	1.4
6.5	H-47	hybrid	128	108	1.8
8	174	SMIN	127	103	0.1
9	173	SMIN	126	111	1.0
10	163	SMIN	124	123	0.1
11	H-96	hybrid	123	108	1.7
12	52	COHIO	122	154	0.3
14.5	103	NCMIS	120	142	1.5
14.5	164	SMIN	120	127	0.1
14.5	222	SOHIO	120	116	0.1
14.5	186	SCHMIN	120	130	0.0
17	41	IND	119	122	0.2
19	242	MO	118	112	1.3
19	195	CMIN	118	119	0.9
19	172	SMIN	118	114	0.3
22	180	SMIN	117	117	0.6
22	42	IND	117	103	0.5
22	217	SOHIO	117	121	0.2
24	191	CMIN	116	113	0.6
25	216	SOHIO	115	122	0.3

^aCanker was scored as follows:

0--no canker

1--light infection, no detrimental effects

2--moderate infection, some open cankers

3--heavy infection, large cankers present
secondary pathogens causing wood decay

stands, families within stand, and clones within family within stand were significant (Table 2).

Trees from stands in Minnesota, Michigan, Ohio, and Indiana were most resistant to stem canker whereas those from Mississippi, Nebraska, Oklahoma, and Kansas proved least resistant (Table 3). Stands from the prairie and southern states all averaged greater than a 1.5 canker rating while the more northern and eastern stands all averaged less than a 1.5 in canker rating. Correlation of survival and canker data was highly significant ($r=.95$). Stands with low survival rated high in occurrence of stem canker, whereas stands exhibiting high survival rated low in occurrence of stem canker.

Waterman (1957) found that the degree of susceptibility to Dothichiza populea varied among different poplar species and hybrids. In the Michigan State University provenance plantation, however, differences in resistance to stem canker among P. deltoides families were probably not attributable to the genetics of individual trees. Dothichiza populea is a widespread pathogen in eastern and central United States (Waterman, 1957), but does not ordinarily cause serious injury to poplar except in young plantations or in trees weakened by other factors. High stem canker occurrences associated with prairie and southern stands were probably a result of the poor adaption of these trees to the Kellogg Forest site. The

resultant environmental stress would have increased the susceptibility of these families to stem canker.

The P. nigra clones were highly susceptible to the stem canker, with large perennial trunk cankers common (Figure 8). Mortality among these clones due to stem canker was beginning to occur in the oldest replication. Hybrid sources were not as susceptible as the Italian clones but in some cases large trunk cankers did form. Unless the P. nigra and Populus hybrid clones show greater canker resistance on a better bottomland "poplar site," it is doubtful whether they have any commercial potential, except in very short rotations.

Leaf Flushing

Actual dates of leafing out ranged from May 5 to May 16. Differences in flushing date between stands, families within stand, and clones within family within stand were significant (Table 2). Error variance, which measures the variation from plot to plot of the same clone represented only 10 percent of the total variation (Table 5). This indicates that leaf flushing date in cottonwood is genetically conditioned and not greatly influenced by microsite. Wilcox and Farmer (1967) and Ying (1974) also found foliation date to be under fairly strong genetic control.

In general the earliest trees to break bud were those from the northern latitudes, whereas southern trees

Figure 8. Large perennial stem cankers were common on the P. nigra clones.

Figure 9. Epicormic sprouting and poor form associated with the P. nigra clones reduce their desirability in long rotation plantations.



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Table 5.--Components of variance derived from mean squares for height, diameter, stem canker, and leaf flushing.

Source	Height	Diameter	Canker	Flushing
Stand	24.627	89.486	.297	3.135
Family/Stand	24.528	65.849	.134	1.343
Clone/Family/Stand	23.988	97.629	.180	1.298
Error	101.061	281.140	.408	.656

Table 6.--Components of variance expressed as a percentage of the total genetic variation.

Source	Height	Diameter	Canker	Flushing
Stand	34	35	48	55
Family/Stand	34	26	22	23
Clone/Family/Stand	32	39	30	22

took longer to begin growth (Table 3). There were some variations in this north to south trend. The Michigan source was latest to leaf out while the sources from Kansas, a more southern location, were the earliest to break bud. In both cases each stand was represented by only one family, so the results are not conclusive. The Italian and hybrid sources were intermediate in time of leafing out, the hybrids averaging slightly longer than the P. nigra clones to break bud.

Practical Recommendations

Among the P. deltoides families represented in the Kellogg Forest plantation, clones from stands in Minnesota proved to be the fastest growing. These trees averaged 8.5 m. (27.8 feet) in height and 10.3 cm. (4.07 inches) in diameter in seven years of growth. Resistance to canker was also high in these Minnesota clones.

Hybrid poplar sources and the two families of P. nigra did show superior growth when compared to the P. deltoides clones, but they were also very susceptible to canker infestation. In addition, the P. nigra clones showed severe epicormic sprouting (Figure 9). Canker induced early death, mechanical failures, and reduction in wood quality resulting from canker wounds and epicormic sprouting severely reduce the potential of these sources for use in long rotation plantations. They may have some application, however, in "silage" plantations where rotations are five years or less (Steinback et al., 1972).

Results of the components of variance analysis are given in Table 5 and Table 6. If variance components are expressed as a percentage of the total genetic variation, the amount of variation among stands relative to that among families and among clones is expressed. Knowledge of the amount of variation associated within each component indicates at which level selection will achieve the greatest genetic gain per generation.

The components of variance attributable to stand represents 33 and 35 percent of the total genetic variation in height and diameter. For stem canker and leaf flushing the stand component represents 48 and 55 percent of the total genetic variation. Differences between stands were significant with approximately one-third to one-half of the total genetic variation attributable to the stand of origin. From a practical standpoint this information can be valuable in directing further improvement work. One-third of the potential gain in height and diameter could be realized by selection from the best stands. Further gain could be realized by selection of the best families within stand and the best clones within family within stand. From an economic viewpoint, stand selection is most desirable because the expected gain can be realized immediately without waiting for the more expensive and time-consuming family and clonal tests.

Results from the provenance test indicate that more northerly and easterly stands produced the best trees

for planting in Michigan. Trees from the prairie and southern states were not well-adapted to the Michigan environment, as indicated by their lower survival and canker susceptibility. Since the trees were only planted on one site, however, there was no opportunity to evaluate genotype X site interaction. Further testing of these clones is necessary to determine if differences in mortality, growth, and canker susceptibility in native cottonwood clones are significantly influenced by site. Another limitation associated with a small scale provenance test using a species as wide-spread as P. deltoides is that some parts of the range were not sampled by the test, while some parts that were samples were not well-represented. Therefore, doubts as to the extent of variation of this species still exist. Further testing is necessary before more specific recommendations can be made concerning the best origins of eastern cottonwood for planting in Michigan.

CHAPTER IV

ROOTING STUDIES

Introduction

Root formation and growth are critical factors in establishment of poplar plantations from hardwood stem cuttings; two experiments were initiated to study genetic variation in and phenology of rooting. The objectives of the experiments were:

1. To evaluate differences in root production by cuttings from selected P. deltoides and P. nigra families and Populus hybrid clones grown in controlled environment and nursery conditions.
2. To compare rapidity of root initiation and root growth rate of the selected poplar families and clones in a controlled environment.
3. To determine if rooting habit significantly influences height growth.

Materials and Methods

Two studies, one in the Michigan State University Tree Research Center, and one in controlled environment facilities, Forestry Department, were initiated in Spring, 1975, to test rooting ability of selected Populus sources. Ten P. deltoides families, one P. nigra family, and one

Populus hybrid were selected from the Kellogg Forest provenance plantation. An attempt was made to select trees equally from above average, average, and below average height classes. Because of the low availability of good cutting material in the below average height class, most sources collected were in the above average or average height class. Hardwood cuttings were made in the two 1970 replications of the plantation in February 1975. They were cut to a uniform 20 cm. (8 inch) length, graded, and stored in moist sphagnum moss at 6°C until the time of planting.

Field Study

The field study was planted on May 9, 1975. The soil was a Kalamazoo sandy loam, a well drained soil with a sandy loam to loam plow layer. Weeds were controlled periodically by hand. A split plot design with four tree plots and a 0.6 m. by 0.6 m. (2 by 2 feet) spacing with 1.2 m. (4 feet) between clones was used.¹ Date of bud break for each cutting was observed during May, while height of each surviving cutting was recorded just before harvest on September 17, 1975. A portion of the root system of each cutting was sampled by removing a soil cube 30 by 30 by 20 cm. (12 by 12 by 8 inches) around the cutting (Figure 10). The soil was washed from the roots with a water spray. Number of roots and dry weight of roots (exclusive of cutting stem) were recorded for each cutting.

¹Because of poor survival of the cuttings the field study was analyzed as a completely randomized design.

Growth Chamber Study

Rate of root growth was followed by growing cottonwood cuttings in glass tubes (40 cm. long by 4.7 cm. diameter) (Figure 11) (Heninger, 1973; Bilan, 1964). The soil used in the growth chamber was taken from the field study nursery bed. Environment in the growth chamber was maintained at the following conditions:

Photoperiod:	14.5 hours
Light Intensity:	4050 foot candles
Temperature:	Day--23°C
	Night--12°C
Relative Humidity:	55-70 percent

The soil in the glass tubes was saturated periodically to maintain adequate moisture levels.

The design of the experiment was a randomized complete block with one cutting of each clone per block (Figure 12). Date of bud break and date of first root appearance were recorded. Growth of roots down the sides of the glass tubes was followed by tracing the root elongation at three day intervals on acetate sheets affixed to the tubes.

The harvest of individual cuttings was done 40 days after the appearance of the first roots. Soil and rooted cutting were washed from the glass tube by means of a water spray. Dry weight of roots and number of roots were recorded for each cutting. All data was subjected to analysis of variance.

Figure 10. A portion of the root system of each cutting was sampled by removing a soil cube along with the cutting.

Figure 11. Rate of root growth was observed by growing cuttings in glass tubes (40 by 4.7 cm.).

Figure 12. General view of the design of the growth chamber study.



Results and Discussion

Field Study

In general, survival of the cuttings planted in the nursery study was very low (Table 7). Eighty-nine percent of the cuttings planted did break bud and begin growth, with no significant differences between families in date of flushing (Table 10). But only 31 percent survived the first month after planting and only 20 percent survived until harvest in September. Examination of the non-surviving cuttings in July indicated that no roots had formed.

As an explanation for this low survival, precipitation and temperature data for the months of May and June are presented in Table 8 and Table 9. During May, when cuttings were first beginning to grow, average maximum and minimum temperatures were both 3°C above normal. More significantly, precipitation for the months of May and June were recorded as below average, with all of June's rainfall occurring during the last week. The unusual temperature and precipitation patterns would have placed the non-irrigated unrooted cuttings under considerable physiological stress. The high May temperatures favored a rapid flush in shoot growth and expansion of a relatively large transpiratory leaf surface. Then high June temperatures, combined with the three-week drought, created a moisture stress condition that only the most vigorously rooting families were able to withstand.

Table 7.--Comparative survival of Populus cuttings used in the field and growth chamber rooting studies.

Sources in Field Study	Sources in Growth Chamber Study	Origin	% Surviving to Harvest	
			Field	Growth Chamber
3824	3824	Italy	100	100
-	H-48	hybrid	-	100
192	192	CMIN	0	0
193	193	CMIN	0	0
163	-	SMIN	25	-
52	52	COHIO	33	75
-	164	SMIN	-	0
249	249	MO	0	0
223	223	SOHIO	0	0
-	184	SCMIN	-	100
279	-	NILL	17	-
224	224	SOHIO	0	0

Table 8.--Average daily maximum and minimum temperatures (°C) for May and June 1975 as compared to 1968-1974 mean.

	May		June	
	Maximum	Minimum	Maximum	Minimum
1968-1974	20	6	25	12
1975	23	9	26	13

Table 9.--Total precipitation (cm.) for May and June 1975 as compared to 1968-1974 mean.

	May	June
1968-1974	7.87	9.98
1975	6.81	2.06 ^a

^aPrecipitation occurred in three consecutive days: June 24, 25, 26.

Table 10.--Degrees of freedom and mean squares for height, date of bud break, number of roots per cutting, and dry weight of roots per cutting for the field rooting study.

Source	DF	Height	Date of Bud Break	# Roots Per Cutting	Dry Weight of Roots Per Cutting
Family	3	3105.045*	15.672 ^{NS}	185.071*	4.179 ^{NS}
Error	7	649.786	26.167	34.476	7.662

NS Not significant

* Significant at the .05 level

** Significant at the .01 level

Only four clones survived in sufficient numbers to be harvested in September (Table 7). There were significant differences in height between families (Table 10). P. nigra 3824, the tallest family, grew 121 cm. (4.0 feet) in height during the 131 day growth period, while the best P. deltoides family, 163, grew 72 cm. (2.4 feet) in the same period (Table 11).

There were also significant differences between clones in the number of roots per cutting (Table 10). P. nigra 3824 was the most prolific rooter with an average of 28 roots per cutting. The best P. deltoides family, 279, averaged 22 roots per cutting (Table 11). There were no significant differences between families in the dry weight of roots per cutting however (Table 10). P. nigra 3824 had the highest dry weight of roots per cutting while P. deltoides 163 produced more dry weight of roots per

Table 11.--Mean bud expansion, root growth, and height values for Populus sources represented in the field and growth chamber studies.^a

Source	Beginning of Bud Expansion (Days)	Dry Weight of Roots (gm/cutting)	First Root Appearance (Days)	# of Roots	Root Growth ^b (cm/day)	Height (cm)
<u>Growth Chamber</u>						
H-48	2.5 a	.662 a	5 b	25 a	3.48	18 a
3824	2.5 a	.531 ab	8 ab	50	1.98	19 a
184	1.3	.267 bc	12	27 a	1.29	14
52	9.0	.217 c	30	6	1.67	3
<u>Field Study</u>						
3824	17	4.578		28 a		121 a
52	21	3.917		12 b		48 b
163	19	4.329		12 b		72 ab
279	16	1.576		22 ab		56 b

^aMeans followed by a common letter are not significantly different (LDS .05).

^bCumulative average growth rate of the three most vigorous roots.

cutting than any other cottonwood family (Table 11; Figure 13).

P. nigra 3824 was the best overall family in the nursery study with respect to number of roots per cutting, dry weight of roots per cutting, and height (Table 11). P. deltoides 279 had a high number of roots per cutting, but ranked lowest in dry weight of roots per cutting and second lowest in height. The two other P. deltoides families, one taller and one shorter than 279, had a lower number of roots per cutting but the roots had more dry weight than the roots of 279. These limited data indicate that the correlation between root habit and first year height growth of cottonwood is not strong.

Growth Chamber

Survival of cuttings planted in the growth chamber was also low. Ninety-eight percent of the cuttings planted did break bud and begin growth, but only 38 percent survived the entire growth period. Harvest of the non-surviving cuttings at the end of the growth period indicates that they had failed to produce roots. There were significant differences between the surviving families in date of bud break (Table 12).

Low survival of poplar cuttings in both the field and controlled environment studies is probably related in part to the length of time the cuttings were kept in cold storage before being planted. Several of the families

Figure 13. Comparison of the four Populus families represented in the field study. (A) P. nigra 3824 (Italian origin) was the best over-all family with respect to number and dry weight of roots per cutting. (B) P. deltoides 279 (North Illinois origin) had a high number of roots per cutting, but the roots were small and did not represent a large dry weight. (C) (D) P. deltoides 163 (South Minnesota origin) and 52 (Central Ohio origin) both had a lower number of roots per cutting but they were large and represented a greater total dry weight.

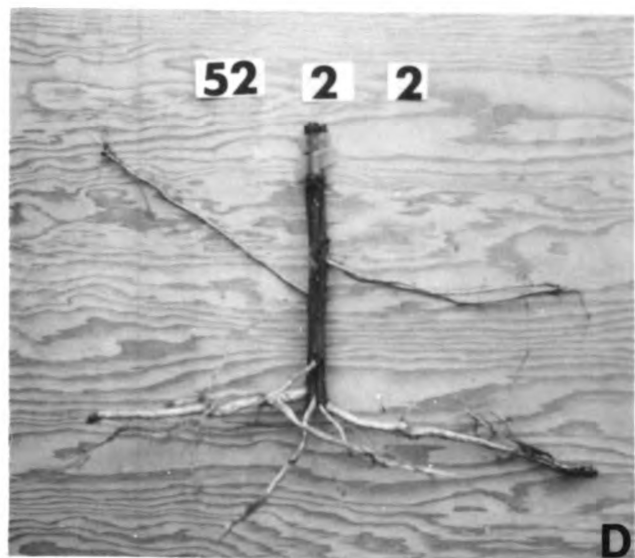
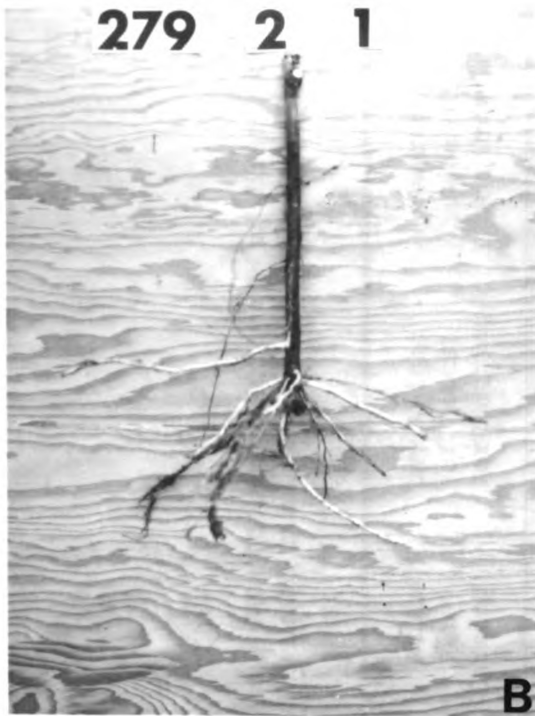


Table 12.--Degrees of freedom and mean squares for height, date of bud break, date of first root appearance, number of roots per cutting, and average rate of root growth for the growth chamber study.

Source	df	Height	Date of Bud Break	Date of First Root Appearance	# Roots Per Cutting	Dry Weight of Roots Per Cutting	Average Rate of Root Growth
Family	3	231.062**	49.229**	513.229**	1297.562*	.156*	3.689 ^{NS}
Error	9	5.433	.563	14.118	25.618	.032	1.710

NS Not significant

* Significant at the .05 level

** Significant at the .01 level

that did not survive in the later growth chamber and field study did produce roots in a pilot study established on March 12, 1975. Evidently the longer period of storage did contribute to a reduction in rooting ability. Physiologically the poplar cuttings were ready to begin growth at the time of collection in late February (Farmer, 1966). But long periods of storage lead to a lessening of food reserves within the cuttings, which is an important factor in the production of roots (Bloomberg, 1963).

Differences between families in date of the first root appearance on the surface of the glass tube were significant (Table 12). P. deltoides 184 broke bud earliest but roots were not observed until 12 days later (Table 11). Hybrid-48 and P. nigra 3824 took longer to break bud, but their roots appeared faster than in the other families. P. deltoides 52 began bud growth latest and was the slowest family to initiate root growth.

Differences between families in number of roots and dry weight of roots per cutting were significant (Table 12). Hybrid-48 had the largest dry weight of roots, but was second in number of roots per cutting. P. nigra 3824 again proved to be the most prolific rooter with an average of 50 roots per cutting, but was second in dry weight of roots. P. deltoides families averaged lower dry weights of roots and fewer roots per cutting than the Italian or hybrid sources (Figure 14). Differences in the average rate of growth for the three most vigorous roots were not

Figure 14. Comparison of the four Populus sources represented in the growth chamber study. (A) P. nigra 3824 (Italian origin) proved to be the most prolific rooter. (B) Hybrid-48 (P. X euramericana 'erecta') was second in number of roots per cutting but had the largest total dry weight of roots per cutting. (C)(D) P. deltoides 184 (South Central Minnesota origin) had a larger number and dry weight of roots per cutting than the other P. deltoides, 52 (Central Ohio origin), which had the lowest number and dry weight of roots per cutting.



significant in this experiment (Table 12). Hybrid-48 exhibited the best rate of root growth, with the Italian and P. deltoides sources showing considerably slower rates of root growth.

Differences between families in height growth were significant (Table 12). Hybrid-48 and P. nigra 3824 were the tallest of all families at 18 cm. (0.59 feet) and 19 cm. (0.62 feet) respectively.

Conclusions

Poor survival of the cuttings did not allow for a comparison between nursery and growth chamber data, as only two families were represented in both. The P. nigra 3824 family was the most prolific rooter in both studies. It had the highest average dry weight of roots per cutting in the field and was second in dry weight of roots per cutting in the growth chamber. P. nigra 3824 was also one of the earliest families to break bud and was the tallest growing in both studies. P. deltoides 52 had the lowest number of roots per cutting, was the shortest, and was the latest family to break bud and begin root growth in both studies.

Results from both the field and growth chamber study indicate that number of roots per cutting and dry weight of roots per cutting are not correlated (Table 11). Some families produced a large number of roots, but they were small and did not represent a large total dry weight; other families produced a lesser number of roots, but the

roots were larger and represented a greater total dry weight. Clonal differences in root ability of poplars have been reported by Bloomberg (1963) and Farmer and Wilcox (1967). Results from the present studies indicate that there are also differences in rooting habit among the cottonwood families represented in the Kellogg Forest provenance plantation.

On the basis of field and controlled environment data, P. nigra 3824 and hybrid-48 were superior to the P. deltoides families. In general, they had a faster rate of shoot and root elongation, and they produced more roots of a greater total dry weight in a shorter time. Results from the provenance study reported earlier also showed that P. nigra and hybrid sources were superior cottonwood clones in height and diameter. But the Italian and hybrid sources are more susceptible to canker infestation and probably would not survive in a long rotation plantation. Further research, therefore, is necessary to determine the potential of the P. nigra and hybrid clones in short rotation intensive culture systems.

Two P. deltoides families, 184 and 163, proved to be significantly better than other native cottonwood families represented in either the field or controlled environment study. P. deltoides 163 exhibited the greatest growth of any native cottonwood family in the field study. While 163 produced a low number of roots per cutting, the total dry weight of these roots was greater than other

P. deltoides families. Family 184 exhibited good height growth in the controlled environment study. It produced more roots and had the largest dry weight of roots per cutting than any of the other native cottonwood families represented in the growth chamber study.

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