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Michigan State University

PH.D. 1984

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By

Lincoln M. Moore

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1984

ABSTRACT

THE MAJOR INSECTS AND DISEASES AFFECTING INTENSIVELY GROWN HYBRID POPLARS ON PACKAGING CORPORATION OF AMERICA (PCA) LANDS IN CENTRAL LOWER MICHIGAN

By

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Intensively grown hybrid poplar trees are vulnerable to attack by numerous pests. The most important pests in this study were poplar-and-willow borer, *Cryptorhynchus lapathi* (L.); poplar-gall saperda, *Saperda inornata* (Say); willow-shoot sawfly, *Janus abbreviatus* (Say); tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois); septoria canker, *Septoria musiva* Peck; marssonina leafspot, *Marssonina brunnea* (Ell. and Ev.) P. Magn.; and melampsora leaf rust, *Melampsora Medusae* (Thum.).

Septoria canker attacks the main stem and branches of susceptible trees; clones with *P. trichocarpa*, *P. maximowiczii*, and *P. laurifolia* parentage were the most susceptible. Trees die when girdled by stem canker, or if mortality does not occur, infected trees sometimes break from wind, ice, or their own weight. Hybrids with *P. deltoides* and *P. euramericana* parentage were the most tolerant to septoria infection in Michigan.

The poplar-and-willow borer was the most important insect of intensively cultured hybrid poplars. It attacked the bases of the young trees 1.8 to 7.4 cm in diameter and then attacked higher up the main stem as trees' heights and basal diameters increased. Light to moderately attacked trees showed little wood degrade or damage, while some heavily infested trees were killed or broken due to wind, ice, snow, or their own weight.

The poplar-gall saperda attacked the bases of trees with a basal diameter of 1.3 cm or larger, and the number and position of attacks on the main stem increased with increased tree height and diameter. The accumulated impact of saperda was: killed--4 percent; top-killed--11 percent; galled, but no apparent injury--65 percent; non-galled trees--2 percent; other organisms--18 percent. Mortality of 4 percent after 4 years is no more than might be expected from most other causes and is certainly a minor concern for biomass production. The average height of top-killed trees was significantly shorter than the average height of uninjured trees.

The tarnished plant bug caused stem lesions on several clones at the nursery during the summer of 1983. Stem lesions were heavy on 'Wisconsin 5': 82 percent of the trees had at least one lesion (average 1.6 lesions per whip). NE-359 was the most tolerant clone with only 0.5 percent injured.

The population of the willow shoot sawfly was heaviest on nursery whips less than 25.4-cm long. There appeared to be two or more generations per year with peak attacks in late July and early August. The level of attack varied from none for DN-17, DN-18, and DN-19 to heavy for DN-55. DN-9, DN-34, WIS-5 and NC-5258 were moderately infested by the sawfly.

Marssonina leaf spot infection ranged from none to severe, depending upon plantation location and time of year. Trees adjacent to old stands infected with marssonina were usually attacked during the first growing season. Trees growing in plantations previously infected by marssonina had a higher incidence of leafspots than trees in previously uninfested plots. Infection caused premature leaf drop and some branch breakage.

Melampsora leaf rust attacks the underside of the leaf and causes premature leaf drop. In the nursery, infected clones were 50 percent defoliated by mid-August, and by mid-September infected whips were about 99 percent defoliated. Clones with *P. jackii* parentage were highly susceptible to infection by melampsora and were therefore rogued from the nursery. Clones NE-19 and NE-20 showed no sign of defoliation and had only a trace of melampsora on a few leaves.

Dedicated to my wife, Catherine Moore;
children, Catherine and John;
parents, Tyler and Beatrice Moore;
and aunt, Emmie Moore.

ACKNOWLEDGMENTS

I wish to express my gratitude to Dr. Gary A. Simmons and Dr. Louis F. Wilson, Co-chairmen of my guidance committee, for their advice, encouragement and assistance throughout this study and my graduate program. My sincere thanks to committee members Dr. Donald I. Dickmann, Dr. John B. Hart, Jr., and Michael E. Ostry for their suggestions and advice, and for their reading and criticism of the manuscript. I also thank William Main for his help in analyzing some of my data; Robin Bolig, CPT specialist, and Melinda Mendoza, clerk trainee, for their excellent cooperation and assistance in producing the text. Appreciation is extended to the North Central Forest Experiment Station for funding my research.

I wish also to thank Packaging Corporation of America for their cooperation and use of their plantations and clonal nursery for this study.

I deeply appreciate the assistance of George C. Heaton, Michael Morin, and Michael Kurziel in the collection of field data and the selection and maintenance of study plots.

Finally, I acknowledge my wife and family for their undying encouragement, support, and patience during this study and manuscript preparation.

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INTRODUCTION

The demands for raw materials from our Nation's forest lands are of great concern to forest managers. These demands are increasing while our timberland base is decreasing (USDA 1973). This decreasing land base is due in part to the wilderness acts, to developers purchasing timberland for new home sites, resorts, etc., and to farmers converting the timberland to agricultural land. The loss of good timber-producing areas has prompted forest managers to assess all timber sites and make recommendations to improve production on each. On many of these sites, short-rotation plantation culture of fast-growing trees is a viable option.

Over the past 50 years insects and diseases have presented many problems to forest managers in established plantations. These pest problems have intensified in several areas due to planting monocultures where pest population densities usually increase rapidly due to the abundance of host material. Organisms that were minor pests in natural stands may reach outbreak levels in a very short time in intensively cultured plantings.

The majority of planted monocultures, to date, have been composed primarily of the rapidly growing conifers.

Recently, forest managers and researchers in the South and the North Central States began experimenting with intensive plantation culture of genetically improved *Populus* clones. In the South, research was concentrated on superior or selected cottonwoods (*Populus deltoides*), while in the North Central States, research was focused on genetically superior *Populus* hybrids. Intensive culture not only implies using superior stock, but also improving soil nutrient levels, soil moisture regulation, competition control, and site preparation. Implementation of these cultural methods results in a short rotation forest crop that is basically an agroecosystem.

As the total acres of planted hybrid *Populus* increase, insect and disease problems will also increase. To date there are about 150 species of insects and 50 different diseases that attack natural growing *Populus*. Wilson (1976) found at least 15 insects and 5 diseases important as pests in *Populus* nurseries and clonal outplantings.

Packaging Corporation of America (PCA), a Tenneco Company, became involved in short rotation intensive culture management in 1974 with the inception of their intensive forestry program. In 1977 the Intensive Forestry Department established its hybrid poplar clonal nursery on an old farm site about 16 km south of their mill in Filer City, MI. The nursery contained both stool and rooting beds where superior stock is grown for outplanting. The intensive forestry program intends growing a minimum of 120 thousand cords of wood per year on company-owned land on a continuous basis.

To accomplish this production goal PCA plans to plant 12 thousand ha to hybrid Populus, and to intensively manage an additional 12 ha of natural timber stands. PCA sees their investment in intensively cultured hybrid poplars as the first step in assuring the availability of wood for their Filer City mill, which uses a mixture of 50 percent poplar, aspen, or birch and 50 percent oak, maple, or other dense hardwoods in the manufacture of corrugated paper. Short rotation intensive culture (SRIC) juvenile hybrid material contains short fibers with thin cell walls, which are easily collapsed into the desired ribbon for bonding.

From 1974 to 1983 PCA outplanted about 2 thousand ha of Populus in several counties in Michigan's lower peninsula. These industrial plantations were established with multiple clones of assorted poplar hybrids. In 1978, land managers at PCA observed numerous insects and diseases on several clones in both the nursery and the young plantations. They noted that some clones were heavily injured while others were not. As this suggested a wide range of host susceptibility or tolerance to pests, in 1980 I installed several research plots to evaluate pest incidence. I decided to study the incidence of poplar pests on PCA lands because it offered an opportunity to research pest organisms in large-scale plantations on industrial lands. In this manner trees and pests could be examined in a normal operational setting instead of the small research plots that are planted and managed by researchers.

OBJECTIVES

The objectives of this study were: (a) to identify the major insects and diseases of intensively cultured hybrid poplars; (b) to assess the damage and impact of the injurious pest species; (c) to determine insect and disease resistance/tolerance to known clones of hybrid poplars; and (d) to design a plan for managing hybrid poplar pests.

MATERIALS

Study Areas

Packaging Corporation of America, Woodland Division, is located in the Filer City mill, Filer City, Michigan. The Filer City mill currently utilizes about 250,000 cords of wood per year. The Woodland Division manages about 24 thousand ha of land in Michigan's lower peninsula, of which 12 thousand ha are forested and another 12 thousand ha have been allocated for intensive management practices. PCA has a nursery from which it produced all its stock. So far PCA has planted hybrid poplars in Benzie, Kalkaska, Lake, Manistee, Mason, and Osceola Counties. Study plots were located in Benzie, Manistee, and Mason Counties; clonal trial plantings were located in Mason County (Figure 1).

Nursery

PCA's clonal nursery is located in Freesoil, MI, Mason County (T20N, R16W, S30) (Figure 1). The nursery was established in 1977 by the Intensive Forestry Department on 7.9 ha of an old farm site about 6.2 km south of the Filer City mill (Figure 2). It contained both stool and rooting beds. These areas were originally planted with 150 different clones (Appendix I) and watered using both overhead and trickle irrigation systems.

Each year the stool beds produced coppiced whips that were harvested during the dormant period, inspected for pest organisms, and cut into 7 to 51 cm long sections with a minimum diameter of 9 mm. Pest-free cuttings were then placed in plastic bags and stored in a cold room or in a freezer at a temperature just below or just above freezing until they were ready for outplanting. Those cuttings stored through the winter in the cold room were usually

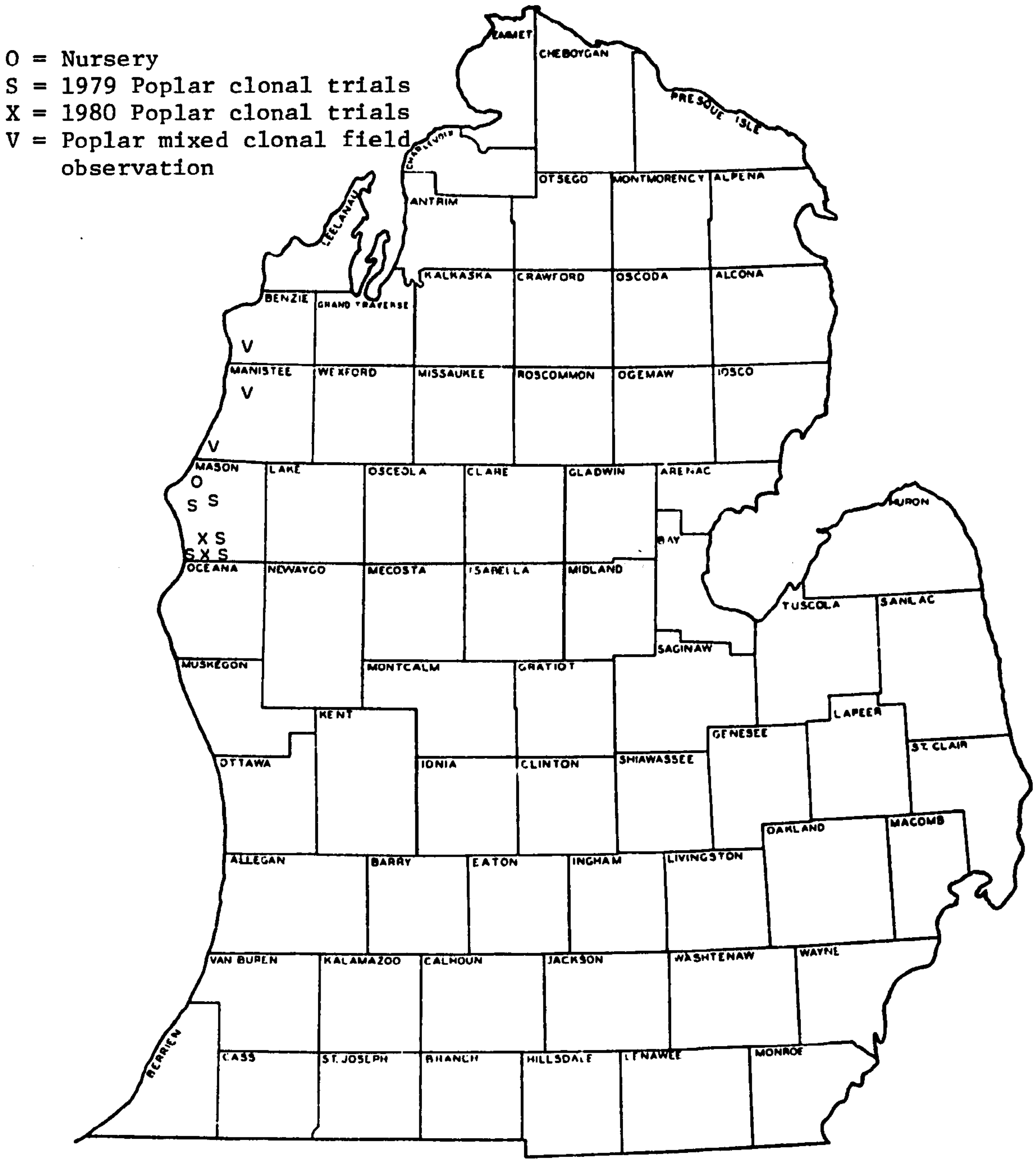

Figure 1. Location of the hybrid poplar study areas in lower Michigan.

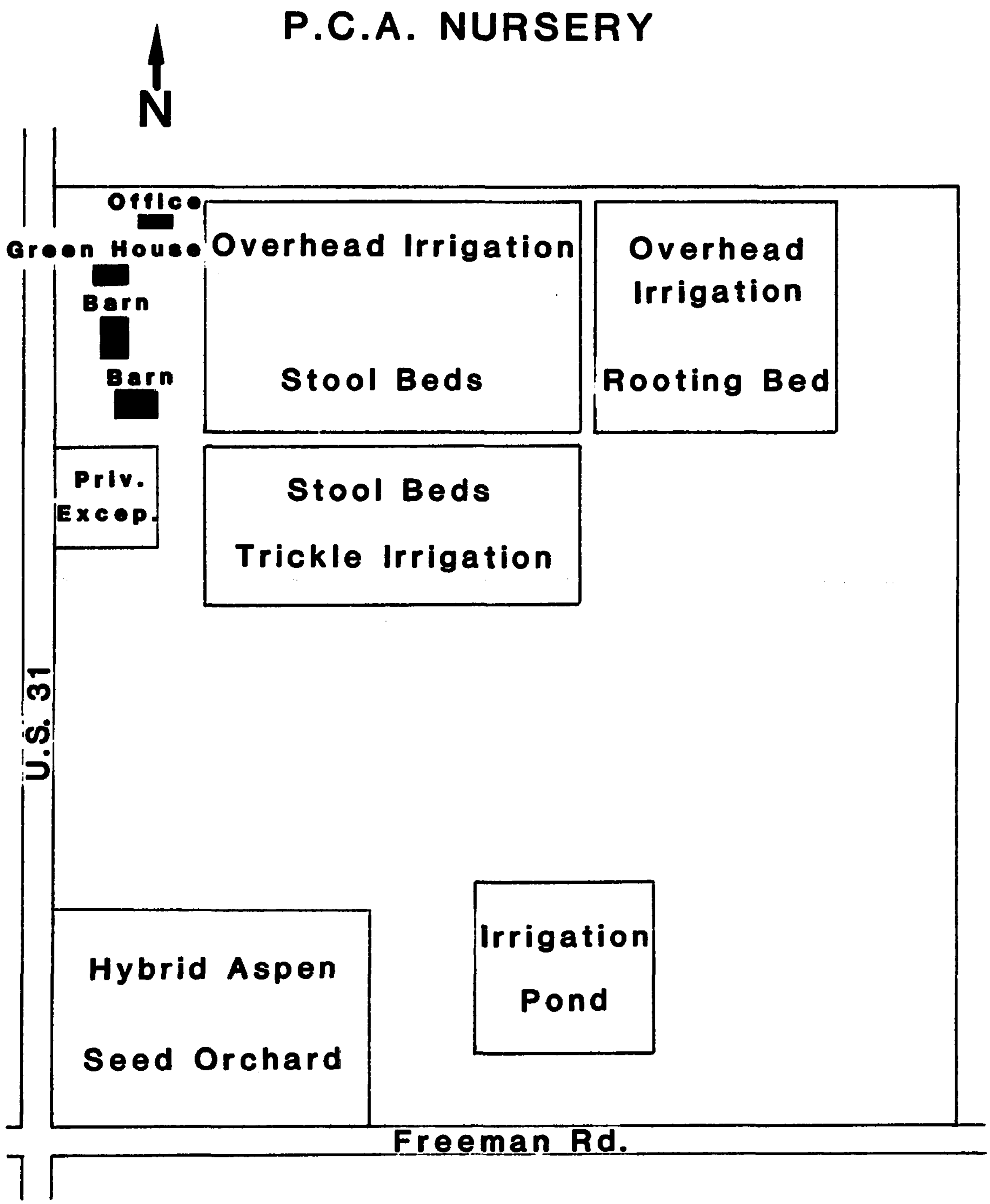

Figure 2. Layout of the PCA's hybrid poplar clonal nursery, Freesoil, MI.

moved to cold storage in early spring to prevent premature bud burst due to warming.

Rooted material lifted from the rooting beds were top and root pruned, and those not fall planted were stored with the cuttings. Rooted stock ranged from 0.5 m to 1.5 m long with a 9.0 mm or larger diameter.

Block Clonal Plantings

In 1978, a hybrid poplar plantation, Benzonia 28, was established in Benzie County (T25N, R15W, S28). This plantation was established with blocks of Raverdeau, NE-353, and a PCA mixture (a random assortment of poplar clones taken from the PCA nursery). This plantation is divided into two sections by a north-to-south natural drainage. The drainage ranged from approximately 3 to 30 m wide. Raverdeau was planted in blocks on both sides of this drainage; NE-353 was planted in a block west of the drainage and mixed with other clones east of the drainage. The distance between the two Raverdeau blocks was approximately 100 m and the distance between the NE-353 block and the mixed planting was about 30 m.

Raverdeau in the west block was established with rooted stock, while 40-cm-long Raverdeau cuttings were planted in the east block. The spacing was 2.4 x 3.0 m in both blocks.

Both the west and east block plantings of NE-353 were established with 40-cm cuttings.

Soil in the east block is loamy clay, and somewhat poorly drained; while soil in the west block (main study area) is sandy, well-to-somewhat excessively drained. However, soil in the western portion of this study area contains more clay and is well drained.

Several clonal trials planted in 1979 and 1980 in Mason County were also used in this study. Clonal trials were named after their respective township and section number. The 1979 clonal trials were: Freesoil 33, Logan 24, Riverton 13 and 23, and Sherman 30. In 1980, Eden 7 and Custer 5 were planted. Each of the 1979 clonal trials was divided into three replications of 60 clones, and five trees per clone, so that each clonal trial contained 900 trees (Appendix II). The soil type in these trials ranged from excessively dry sand to excessively wet silt loam. The 1980 clonal trials were established with three replications of 69 clones, again with five trees per row (Appendix III). Several of the clones used in 1980 were different from those used in the 1979 clonal trials. Soils on the 1980 sites ranged from a somewhat well-drained loam to a wet, compacted clay loam. A brief description of soil types in each clonal planting follows.

Freesoil 33 (T20N, R16W, S33) is a Grandy sandy loam. This is a poorly drained soil with water remaining above the surface for 8 or more months of the year.

Logan 24 (T17N, R15W, S24) and Eden 7 (T17N, R16W, S7) are both well drained Nester loam. This soil is prime agricultural land because of its high natural fertility and retention of artifically applied fertilizer.

Riverton 13 (T17N, R17W, S13) and Custer 5 (T18N, R16W, S5) are on Selkirk silt loam that is somewhat poorly drained. This soil is wet early in the growing season but dry by mid-summer when it forms a compacted crust.

Riverton 23 (T17N, R17W, S23) contains Ogemaw sandy loam and Lamson fine sandy loam. The Ogemaw soil type is somewhat poorly drained and covers about 50 percent of the area. Lamson soil type covers the other 50 percent of the area and is very poorly drained. The water table is usually above the surface most of the year.

Sherman 30 (T19N, R15W, S30) has a Kalkaska loamy fine sand that is somewhat excessively drained. Soil in this area is very dry and sandy.

Mixed Clonal Plantings

In 1976, approximately 2 ha of land adjacent to the PCA nursery were planted with hybrid poplar. This plantation contained a random mixture of at least 40 different rooted poplar clones. During the first 2 years after establishment, weed competition was controlled through cultivation. Due to a heavy septoria canker infection,trees in this plantation were harvested for firewood in 1981. Trees were cut and their tops removed from the plantation, and then the stumps were allowed to coppice during the following growing season. Mid-summer inspection of stump coppice material indicated a very high infection level of septoria canker on new sprouts. This heavy infection forced the nursery manager to destroy all stump coppice material in the plantation to reduce the infection level around the nursery.

The Renwick plantation, Mason County, Sherman 30 (T19N, R15W, S30) was established in 1979 with a mixture of 1.5 m rooted hybrid poplar whips at 2.4 x 3.0 m spacing. The plantation is bordered on three sides by small and mature aspen. The east border contains young planted hybrid poplar and volunteer aspen. The soil within the plantation is Kalkaska loamy fine sand, somewhat excessively drained.

The Lloyd plantation, Mason County, Grant 2 (T20, R17W, S2) was established in 1977 with a mixture of hybrid poplar 25.4 cm cuttings of NE-47, NE-235, and NE-308 at a spacing of x 3.0 m. The plantation is bordered on three sides by small and mature aspen and cherry. The north border contains a hybrid aspen plantation also planted in 1977. Soil within the plantation is Kalkaska sand, excessively drained.

Populus Clones

The genus _Populus_, a member of the willow family (Salicaceae), contains about 30 species widely distributed throughout the northern hemisphere from the southern United States and southern Europe and northern Africa nearly to the limit of tree growth in the Arctic (Wright 1976). Species in this genus easily hybridize naturally or artificially through controlled pollination. The first controlled pollination of _Populus_ was conducted in 1912 by A. Henry, who crossed eastern cottonwood with northern black poplar (Henry 1914). In 1924, Stout and Schreiner at the Oxford Paper Company of Maine started an extensive hybridization project (Wright 1976). Stout and Schreiner (1933) used a numbering system to describe new clones, for example OP-1. Poplar breeders and tree improvement projects still use a numbering system to describe new clones and cultivars

(Dickmann and Stuart 1983). The old Oxford Paper Company designation (OP) was changed to NE when the Northeastern Forest Experiment Station of the USDA Forest Service took over the poplar improvement project; for example, OP-1 = NE-1 (Dickmann and Stuart 1983; Appendix I). Some breeders use a joint letter-number designation, the letter indicates the parents and the number indicates the clone. For example, DN-1 means *P. deltoides* x *P. nigra*. Still other clones are named after the country of origin. For example, I-45/51 means Italy 45/51 (Dickmann and Stuart 1983).

The genus *Populus* is divided into five sections: Turanga, Leucoides, Leuce, Tacamahaca, and Aigeiros. The Turanga and Leucoides sections are of minor importance and were not represented in the present study.

Leuce contains the aspen (subsection Trepidae) and the white poplar (subsection Albidae). Trees in this section occur over most of the northern hemisphere and are economically important (Dickmann and Stuart 1983). The subsection Trepidae contains six species but only *P. tremula*, *P. tremuloides*, and *P. grandidentata* are known to American foresters (Dickmann and Stuart 1983). *P. tremuloides*, and *P. grandidentata* are important commercial species throughout North America. They occur in a wide range of soils and in areas that are either hot or cold or wet or dry. These trees can grow to over 20 m in 20 years or less under normal growing conditions. P. tremula is native to Europe, Africa, and Asia. It is a medium-size tree, and is a commercially important species in its native area.

The subsection Albidae contains one major species, the white poplar (P. alba L.), native to Africa, Europe, and Asia, but was introduced into North America as an ornamental tree and has become naturalized in many areas (Dickmann and Stuart 1983). Currently, it is not grown commercially but has shown excellent growth rates in the northeastern U.S. and southern Canada.

The Tacamahaca section is the largest section in the genus Populus. This section is composed of balsam poplar (P. balsamifera L.), black cottonwood (P. trichocarpa Torr. and Gray), Japanese poplar (P. maximowiczii Henry), narrowleaf cottonwood (P. angustifolia James), laurel poplar (P. laurifolia Ledeb.), Himalayan balsam poplar (P. tristis Fisch.), and heartleaf poplar (P. candicans Stout). Trees within this section grow in a wide range of soils from dry upland to wet lowland sites. Some species are tolerant to frost while others are highly susceptible to frost in spring and fall.

The Aigeiros section is the most important section in North America to poplar culture (Dickmann and Stuart 1983). This section contains the eastern cottonwood (*P. deltoides* Bart. ex. Marsh.) and black poplar (*P. nigra* L.). Several cottonwood species and their hybrids are important commercially. Like Tacamahaca, Aigeiros species grow on a wide range of soils with different moisture and temperature regimes.

Hybrids in the Tacamahaca and Aigeiros sections were mostly used by PCA because they are easily propagated by cuttings, and hybrids within and between these sections have economical potential. Although economically important, the Leuce section (aspens) was not used because of the difficulty of rooting from cuttings. Aspens normally reproduce seedlings from root sprouts or seeds, the latter allowing for a wide range of variability within seedling progenies.

PESTS ENCOUNTERED

From 1980 through 1983, I observed 19 different insects and 10 different diseases on the hybrid *Populus* grown under intensively cultured management at PCA (Table 1). The number of pests present and their impact were evaluated on a case by case basis, because some organisms like the spotted poplar aphid (*Aphis maculatae*, Oestlund) had very high numbers of individuals but there was little injury. In contrast, only one stem canker such as that from septoria (*Septoria musiva* Peck) sometimes caused stem breakage.

Insects were divided into three main categories based on their feeding habits--borers, sapsuckers, and defoliators. Insect borers were identified as stem and/or shoot borers depending on which part of the tree the damage occurred. Sapsucking insects were those insects with piercing and sucking mouth parts that feed on the sap of the tree. No effort was made to separate stem sapsuckers from shoot sapsuckers. Defoliators were those insects that fed on or inside the leaves.

Diseases were also categorized by type of injury. The category "cankers" included all disease organisms observed

Table 1. Insects and diseases observed on hybrid poplars in the PCA nursery and plantations

Categories	Common name	Scientific name
Stem and shoot borers	Poplar-and-willow borer	Cryptorhynchus lapathi (L.)
	Poplar-gall saperda	Saperda inornata (Say)
	Willow-shoot sawfly	Janus abbreviatus (Say)
	Cottonwood twig borer	Gypsonoma haimbachiana (Kearfott)
	Snowy tree cricket	Oecanthus fultoni Walker
Sapsucking insects	Tarnished plant bug	Lygus lineolaris (Palisot de Beauvois)
	Spotted-poplar aphid	Aphis maculatae (Oestlund)
	Oystershell scale	Lepidosaphes ulmi (L.)
	Tuliptree scale	Toumeyella liriodendri (Gmelin.)
	Cottony maple scale	Pulvinaria innumerabilis (Rathvon)

Table 1 continued

Categories	Common name	Scientific name
Defoliators	Cottonwood leaf beetle	Chrysomela scripta Fabr.
	Mourningcloak butterfly	Nymphalis antiopa (L.)
	Viceroy	Limenitis archippus (Cramer)
	Sarrothripus moth	Sarrothripus frigidana Walker
	Blotch leafminers	Gracillariidae
	Leaf rollers	Tortricidae
	Leaf curl midge	Prodiplosis morrisi Gagne
	Short-horned grasshoppers	Acrididae
	Serpentine leafminers	Gracillariidae
Cankers	Septoria canker	Septoria musiva Peck
	Black stem	Phomopsis spp. Cytospora spp. Dothichiza spp.

Table 1 continued

Categories	Common name	Scientific name
Leaf spots	Septoria leaf spots	Septoria musiva Peck
	Marssonina leaf spots	Marssonina brunnea (Ell. and Ev.) P. Magn.
	Septotinia leaf blotch	Septotinia populiperda Wat.
	Venturia shoot blight	Venturia sp.
	Ink spot	Ciborinia sp.
	Leaf blight	Alternaria sp.
	Ring spot	Phyllosticta sp.
Leaf rust	Melampsora leaf rust	Melampsora medusae (Thum.)

that caused either stem (basal or terminal) or branch cankers. Leaf spots contained those disease organisms that caused spots on the leaf surface. Leaf rust contained those diseases that caused rust on the leaf surface.

Pests were ranked in order of importance. The criteria used to determine pest ranking were the 1) pest organism; 2) number of insects or amount of area affected; 3) part of tree affected (leaf, branch, terminal, base, etc.); 4) number of trees affected; and 5) impact on tree growth and development. Each organism was evaluated individually to determine its overall ranking. An effort was made to determine if organisms acting in combination with each other were important. As an example, septoria stem canker and the poplar-and-willow borer were investigated to determine if trees with septoria cankers were more attractive to the poplar-and-willow borer than those without cankers.

Stem and shoot boring insects were the most damaging insects of intensively grown hybrid poplars. Insects in this category infested both stems and shoots of trees within all age classes. The kind of attacks ranged from no apparent damage to severe. The level of damage caused by these insects varied from year to year due to the age and vigor of the trees. For example, if a 1-year-old whip was killed at the base by borers it could resprout the next year that caused either stem (basal or terminal) or branch cankers. Leaf spots contained those disease organisms that caused spots on the leaf surface. Leaf rust contained those diseases that caused rust on the leaf surface.

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The population size of sapsucking insects was higher than that of all other insects combined. Insect populations ranged from very low to very high, yet caused little or no apparent injury. These insects were observed feeding on the main stem, branches, and foliage. Damaged leaves would curl or fold, but they seldom dropped off. Stem and branch damage was usually limited to whips in the nursery or young plantations (less than 3 years old). Sapsucking insect feeding damage occasionally caused stem or shoot lesions, and nursery stock with high numbers of lesions was culled during grading. In the field lesions were easily observed but caused little damage.

Defoliating insects were observed throughout the PCA nursery and plantations, with populations ranging from low to severe (over 75 percent of the tree defoliated). Insect feeding ranged from mining the leaf to consuming the entire leaf to attacking the young shoot. Damage, however, was hard to determine because defoliation often took place early or late in the growing season. If defoliated early, trees would refoliate by mid-summer and then show no signs of injury. Late defoliation usually occurred close to bud set making it hard to distinguish the impact of insect defoliation from the effects of abscission.

Cankers were observed on the main stem and lateral branches of trees in the nursery and young plantations. Canker infection was the most important disease of hybrid poplars. Infection levels ranged from light to heavy with cankers on both the main stem and lateral branches. Trees were rated lightly infected if cankers were confined to the branches, whereas trees with cankers on the main stem were usually considered heavily infected. Stem cankers occasionally caused breakage and provided points of entry for other diseases and insects. Clones identified as highly susceptible to cankers were rogued from the PCA nursery. In severely infected stands tree growth was reduced and in some cases trees with multiple stem cankers were girdled at the point of infection. Several clones had a high level of pest tolerance during the first 4 years, but this tolerance diminished during the fifth year.

Leaf spots and shoot infections were observed on all hybrid poplar clones at PCA. These infections were rated from low to severe based on the time of year observed and the area of leaf surfaced covered. Although not one clone was free from leaf spot and shoot infections, I was unable to determine any measurable injury on any clone. I did, however, determine that heavy spore development by septoria leaf spot aided canker development through spore release throughout the growing season.

Leaf rust infection was light to severe on specific poplar clones at PCA. The infection was most severe in the nursery where overhead irrigation was used. Several clones with common parentage were rogued from the PCA nursery in 1980 and 1981 due to severe levels of rust. Premature leaf droppage of infected trees started in early August, and by late August no leaves were left on the trees.

Pests were ranked mostly by the degree of injury they caused. Those pests not responsible for obvious impact on tree growth or survival were considered minor pests, while those pests causing reduction in growth or survival were considered major pests. The major pests were: 1) poplar-and-willow borer, 2) poplar-gall saperda, 3) willow shoot sawfly, 4) tarnished plant bug, 5) septoria leaf spot and canker, 6) marssonina leaf spot, and 7) melampsora leaf rust.

Poplar-and-Willow Borer

Brief Life History

The poplar-and-willow borer adult feeds on the inner bark of young shoots and is active from late May through late September (Moore *et al*. 1982). The weevils mate 2 to 10 days or more after emergence. Eggs are laid in March and April by overwintering adults and from July through

September by newly emerged adults (Furniss 1972). Eggs are deposited by the female in slits chewed in the bark lenticels and wounds of the main stem or large lateral branches (Matheson 1917).

Depending on the temperature, larvae hatch in 18-21 days and immediately begin enlarging their egg niches (Harris and Coppel 1967). The first external evidence of feeding by the young larvae is the brown frass mixed with tree sap. Larvae tunnel in the inner bark until late fall and then overwinter in small hollowed out chambers. They resume feeding the following spring and tunnel up the center of the main stem as they grow. When nearly ready to pupate, they construct pupal cells at the end of their tunnels. The pupal stage usually lasts from 10 to 12 days during late spring and summer, but if the pupal stage is reached in late September, pupae remain in the cell until the following spring (Doom 1966).

Damage

Feeding damage by the adult poplar-and-willow borer is usually limited to the young shoot tips, resulting in little or no apparent damage. The newly hatched larvae tunnel in the cambium layer around the circumference of the stem. As the larvae mature they tunnel to the center of the tree, sometimes causing it to break from ice, wind, or its own weight. These breaks can occur at the base or any other part of the stem. If the tree breaks at the base it will produce multiple shoots, resulting in a bushy tree with little commercial value. However, if the top breaks, one of the lateral branches will become the terminal shoot, allowing the tree to grow normally. Less severely damaged trees show signs of reduced growth and vigor due to repeated attacks.

Trees repeatedly attacked at the base enlarged somewhat due to callous tissue produced by the tree. Attacked areas can also serve as points of entry for other insects and diseases.

Methods and Materials

A study was conducted from 1980 to 1982 in the Benzonia 28 Plantation. The plantation was established in the fall of 1978 with rooted stock of Raverdeau (*Populus* x *euramericana* 'Raverdeau') and 40-cm cuttings of NE-353 (*P. deltoides* x *P. nigra* var. *caudina*) at 2.4 x 3.0 m spacing.

This is the plantation that is divided into two sections by a north to south natural drainage approximately 3 to 30 m wide. Raverdeau was planted in blocks on both sides of this drainage; NE-353 was planted in a block west of the drainage and mixed with other clones east of the drainage. The distance between the two Raverdeau blocks was approximately 100 m; the distance between the NE-353 block and the mixed planting was about 30 m.

During the summers of 1980, 1981, and 1982, I examined approximately 700 Raverdeau and NE-353 trees in the west block for signs of poplar-and-willow borer attacks. In the east block 710 trees of Raverdeau and about 600 trees within the clonal mixture were examined during 1980 and 1981. The study plot located in the west block consisted of 490 Raverdeau trees and 210 NE-353 trees. The number and position of attacks (base, middle, upper) on the main stem of each tree and the number of stem breakages were recorded.

In the summer of 1980, I measured tree diameter at 0.3 m above the ground. In 1981 and 1982, tree height was measured to the nearest meter and dbh was measured to the nearest millimeter for all trees 1.5 m or taller. Diameter was measured at 0.46 m for trees less than 1.5 m tall. The data were analyzed using Pearson's correlation coefficient.

Results and Discussion

Raverdeau and NE-353 were located in both blocks but only trees in the west block were infested by the poplar-and-willow borer in 1980. These attacks were usually confined to the base of trees that had basal diameters between 1.8 and 7.4 cm. Numbers of attacks at the base ranged from 0 to 20 with an average of 1.60 per tree. In 1981, the average number of new attacks at the base was 0.95 attacks per tree. The mean number of attacks at the middle and upper positions increased from 0 in 1980 to 0.62 and 0.04, respectively.

Pearson's correlation coefficient showed a significant relationship between number and position of attacks and stem diameter and height ($P<0.05$) indicating that as stem diameter and height increase so do number of attacks at positions other than the base (Figures 3 and 4).

Soil in the east block was a poorly drained loamy clay; soil in the west block (study area) was sandy and well-to-somewhat excessively drained. Trees growing in this west block could be stressed during prolonged dry weather as occurred in the summer of 1980, predisposing them to attack by both insects and diseases. This explanation could account for why Raverdeau and NE-353 growing in the west block were attacked by the poplar-willow-borer in 1980.

Raverdeau was established using rooted stock; NE-353 was established from cuttings. Thus, Raverdeau grew faster than NE-353, and it may have been attacked more in 1980

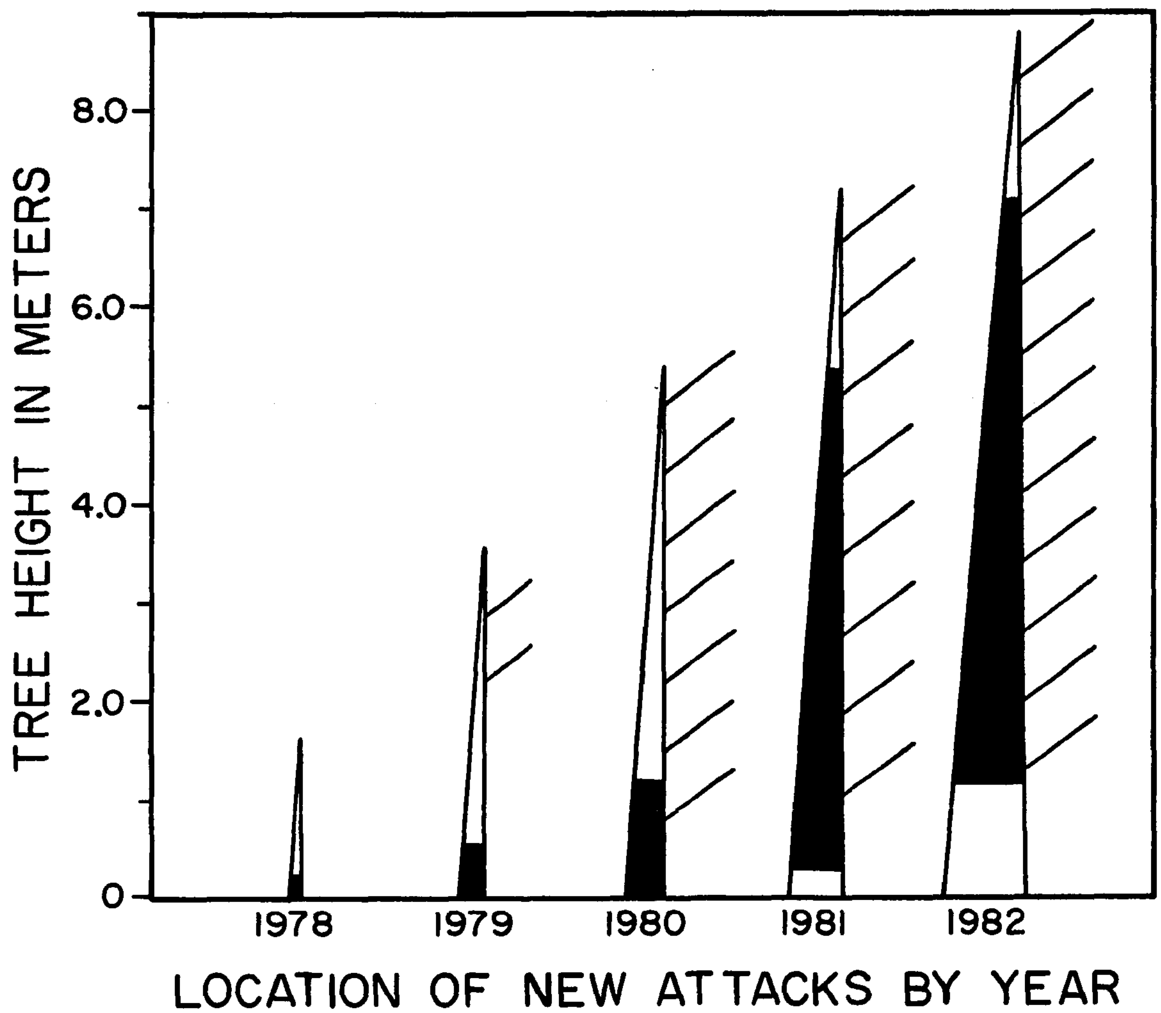

Figure 3. Location of the poplar-and-willow borer attacks on Raverdeau for five growing seasons after planting. Rooted cuttings were planted in the spring of 1978.

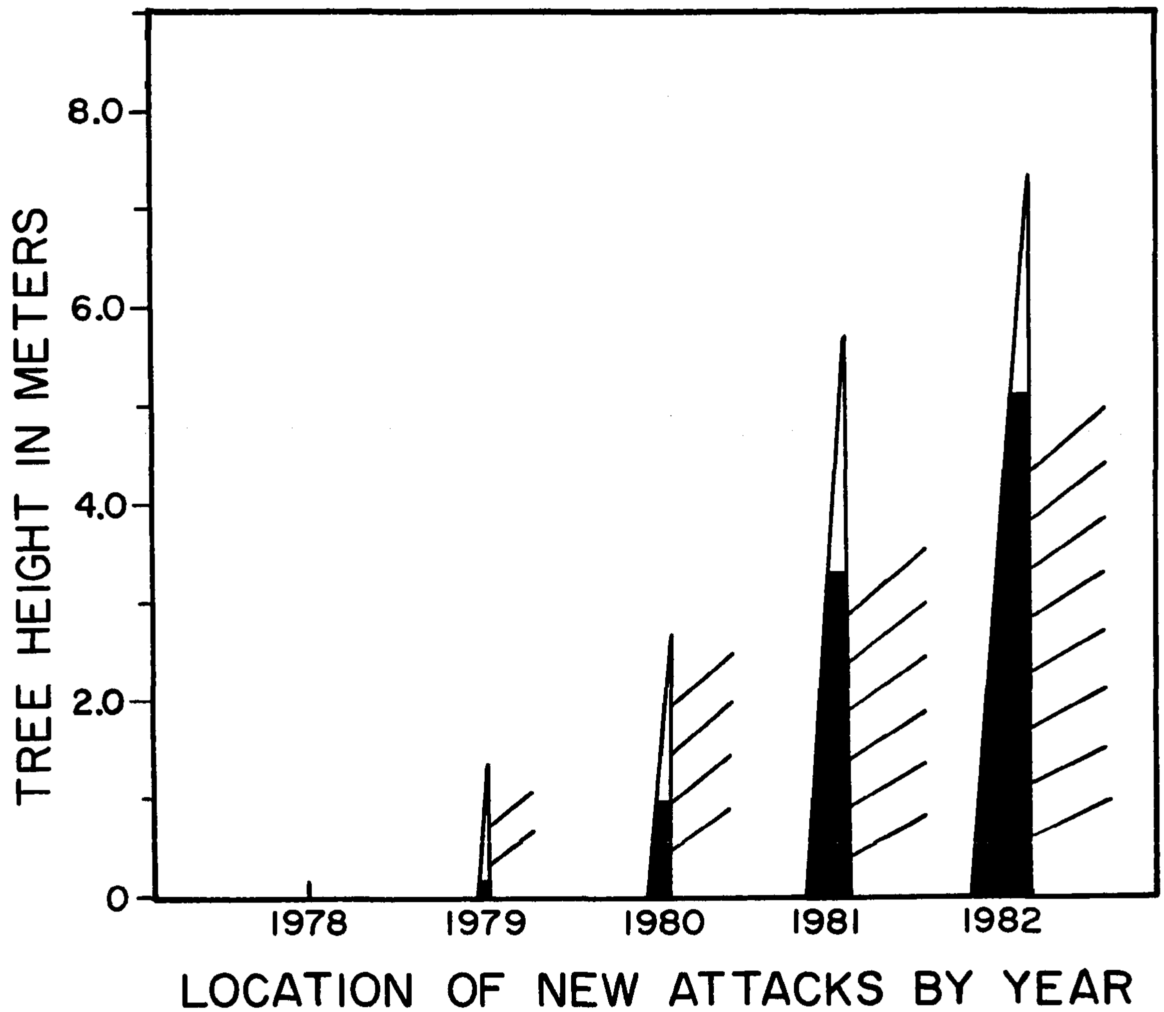

Figure 4. Location of the poplar-and-willow borer attacks on NE-353 by year. No attacks in 1978 due to small basal diameters resulting from planting small, unrooted cuttings in the spring of 1978.

because basal diameters were large enough to support brood development. Morris (1981) observed that the poplar-and-willow borer attacked young balsam poplars more than 2 cm in basal diameter throughout southern Ontario. Harris and Coppel (1967) showed that oviposition begins in 1 year old and older trees. They also observed that brood development generally occurred within the first meter of tree height. This pattern was observed with basal diameter less than 4 cm; however, as tree height and diameter increased, the level of attack moved higher up the main stem. In Raverdeau, several attacks occurred at a height of about 7 m on the main stem.

During 1981, the number of attacks increased in both Raverdeau and NE-353. In Raverdeau the number of attacks begin to increase in the middle and upper portions of the tree, suggesting that diameter was an important factor. Vallee (1979) and Morris (1980) noted that as tree diameter and height increased, the location of attacks moved up the tree. Morris (1981) also reported that borers attacked hybrid poplars 3 to 6 m tall at positions in their trunks where the bark was smoother and thinner.

During the winter of 1981, eight Raverdeau and two NE-353 trees broke off from borer tunneling in the main stems. Several investigators reported tree mortality from stem girdling by this insect or stem breakage at the point of injury from wind, ice, or the tree's own weight (Matheson 1917, Harris and Coppel 1967, Furniss 1972, and Morris 1981). Some researchers have expressed concern that the entrance holes and tunnels constructed by the adult females and developing larvae could serve as entry points for other wood-boring insects and pathogenic fungi. I did not observe any fungal infection or attacks by other wood-boring insects in damaged trees within our study area.

Poplar-gall Saperda

Brief Life History

The poplar-gall saperda adult emerges from May through July, depending on local weather conditions (Britton 1919, Pierson 1927, Nord 1968, and Wilson and Ostry 1980). Newly emerged adults feed on the edges of leaves, along the mid-rib, on the undersurface of the leaf blade, and on the outer tissues of new shoots and twigs. Adult movement is usually relatively limited if oviposition sites are available. Observations by Grimble (1966) suggest that the beetle is a weak flyer and rarely travels more than a few meters. Hussain (1972) said beetle activity was influenced by local weather conditions and reported that on cool days (below 21°C) female beetles rested on leaves or stems, while on warm days (above 21°C) female beetles were active and constructed numerous egg niches.

Mating and oviposition usually take place during the first week after emergence, but oviposition can continue through the end of August (Nord 1968). The female beetles construct one or more "U"-shaped egg niches around the main stem or twig in a ring (Wong and McLeod 1965). A single egg is usually deposited under the flap at the base of each niche (Meyers 1967).

Larvae hatch about 2 weeks after oviposition and feed in the phloem near the necrotic area which borders the egg (Hussain 1972). The larvae then tunnel laterally under the bark, and after boring about 13.0 mm around the stem, they enter the xylem and complete their development (Meyers 1967). Galleries are kept clean of boring frass by ejection through the oviposition slits (Meyers 1967). Late larval instars bore into the center of the stem or twig along its axis (Harrison 1959) and overwinter at the end of this tunnel (Hamilton 1888a). Pupation usually takes place in the gallery during the spring 2 years after oviposition, depending on local temperature and time of oviposition (Hamilton 1888b).

Damage

The adult poplar-gall saperda slightly damages the tree through foliage feeding and oviposition. Larval boring injuries in the cambrium produce the globose swellings or galls around the damaged area. Tunnels in the tree pith cause the tree to break over naturally or from ice, wind, or snow. Damaged areas may also serve as points of entry for other insects and canker fungi such as *Hypoxylon mammatum* (Wahl.) Miller, and *Cytospora chrysosperma* (Pers.) F. (Anderson *et al*. 1979). Trees killed at the base usually resprout without a dominant shoot and grow into a bush of little commercial value. The upper stem of young trees may also be girdled which causes breakage above the point of entry, resulting in lost growth and vigor.

Methods and Materials

During the spring of 1980, two study plots were established within the Renwick plantation to evaluate the effects of *S. inornata*. The stand was planted in the spring of 1979 with 1.5-m-tall whips of mixed hybrid *Populus* clones. The plantation is bordered on three sides by mature native aspen. Plot sizes were 34 x 54 m (plot 1) and 34 x 64 m (plot 2). The plots had 182 and 209 trees, respectively.

On May 6, 1980, whips within each plot were examined for the presence of _S. inornata_ galls on both the main stem and lateral branches. The presence or absence of galls was recorded from 1979 attacks because insect activity had not begun for 1980. The injury class codes were as follows: 0 - no apparent injury; 1 - top of tree killed above the gall (includes broken top at point of gall injury; 2 - tree killed to the base from _S. inornata_ attack at the base; 3 - top of tree killed by other agents (snowy tree cricket, other wood borers, etc.); 4 - tree killed to base by other agents (disease, mice, etc.); 5 - miscellaneous injury (buck rub, deer nip, rabbit feeding, etc.); and 6 - resprout at tree base following some kind of injury to the whip.

On August 6, 1980, gall and injury code data were recorded for 1980. On June 4, 1981, tree heights and tree diameters were recorded for each tree as a measure of 1980 growth. Tree height was measured to the nearest meter and diameter to the nearest millimeter. Measurements were made again on October 27, 1981, and October 1, 1982.

Data collected over 3 years were analyzed using regression, t-test, condescriptive, scattergram, and partial correlation coefficient. During these procedures, data were compared by injury code, height, diameter and number of galls.

Trees included in the first data file had to have a height of at least 1.5 m and a minimum diameter of 13.0 mm, with at least one branch and one stem gall. The second data file included was made using all trees with height $\geq$1.5 m or diameter $\geq$13.0 mm and stem or branch galls.

The last data base consisted of tree height, total stem galls (stem galls 19+79+80+81+82) and total branch galls (branch galls 19+79+80+81+82). These data were then analyzed to determine if there were significant differences between trees with galls versus trees without galls.

Results and Discussion

During the 1979 growing season, 70 percent of the young poplar whips were attacked by the poplar-gall saperda (Table 2). The number of galls ranged from 0 to 8 with an average of 1.6 galls per whip. Ten whips (3 percent) were killed while another 29 (7 percent) suffered top mortality (Table 2). Whips with top kill lost terminal growth of 0.3 to 1.5 m, depending on where the infestation occurred.

In 1980 more than 80 percent of the 2-year old trees had one or more galls, with an average of nearly two galls per tree (range 0 to 12 galls); 35 percent of these galls were on the lateral branches. By the end of the season, 4 percent of the trees died from basal galls. Another 10

Table 2. Accumulative impact of the poplar-gall saperda by damage classes from 1979 to 1982 (388 trees total)

Injury class	Accumulative yearly impact							
	1979		1980		1981		1982	
	No.	%	No.	%	No.	%	No.	%
Killed by saperda	10	3	15	4	17	4	17	4
Top-killed by saperda	29	7	37	10	40	10	44	11
Galled by saperda but no apparent damage	234	60	259	67	253	65	251	65
No-galled (no injury)	74	19	17	4	10	3	8	2
Other injury	41	11	60	15	68	18	68	18

percent were top-killed from galls higher on the stem (Table 2).

Attacks in 1981 produced another two galls per tree, on the average, with nearly 30 percent on the branches. By the end of this season, 4 percent of the trees were killed and 10 percent top killed by saperda, the same as in 1980.

Attacks in 1982 were very similar to 1981 with an increase in the number of galls on the main stem and lateral branches. Tree mortality remained at 4 percent while top kill by saperda increased to 11 percent (Table 2).

Trees attacked by the poplar-gall saperda from 1980 to 1982 showed no significant difference in height growth when compared to uninjured trees using Student's t-test at alpha = 0.05. In fact, of the 311 trees attacked by the saperda only 61 showed signs of growth loss.

Student's t-test at alpha = 0.25 in 1980 showed a significant difference in height between uninjured trees and those galled but without other damage; however, in 1981 and 1982 there was no significant difference between these groups. The t-tests between height of uninjured trees and top-killed trees in 1980 were significant at alpha = 0.1, but in 1981 and 1982 the level of significance was at alpha = 0.25. Galled trees and top-killed trees were significantly different in height at alpha = 0.25 for the 3 years (Figure 5).

One-way analysis of variance (F at 0.05) indicated that there were significant differences in mean heights between injury classes, however, there was no significant difference within classes. Student's t-test at alpha = 0.25 between uninjured trees and trees with one to nine galls showed no significant difference in mean heights; however, trees with ten or more galls were significantly shorter than uninjured trees. No attempt was made to analyze differences between clones because identification of clones was impractical.

These analyses suggest that the poplar-gall saperda is a serious pest in poplar plantations only when damage results in tree death or top kill. Galling alone, unless heavy, causes no significant growth loss. This conclusion is contrary to previous research findings by Grimble (1969), Nord (1968), and Hussain (1972). These researchers reported that saperda was a serious pest in young isolated stands of both native and hybrid *Populus* in northern Michigan. Attacks by the poplar-gall saperda during the first year or two appear to cause measurable growth losses in hybrid poplar plantings because over 70 percent of the attacks are on the main stem. Although some stems will break off and lose height growth, most of those that live produce vigorous

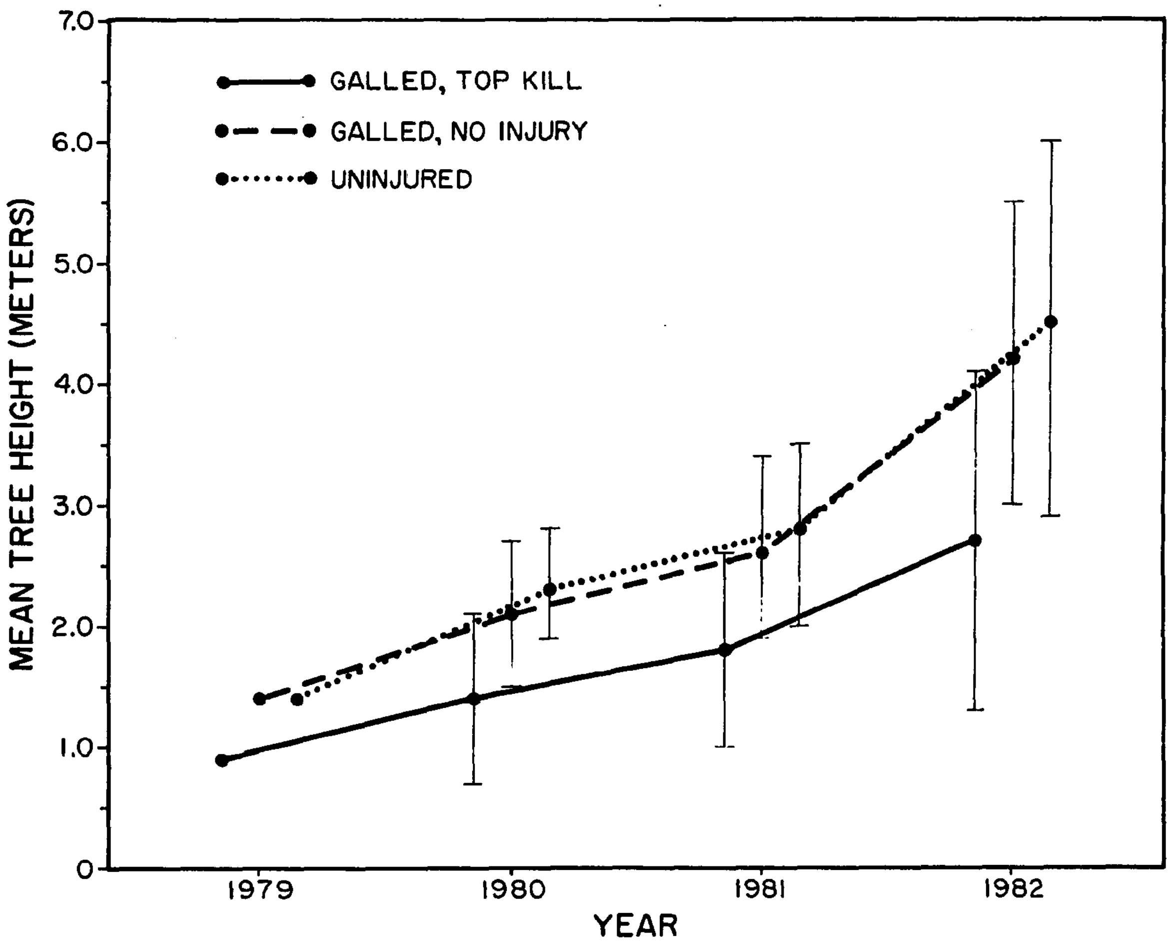

Figure 5. Comparisons of heights of three categories of trees--two categories with saperda galling and one uninjured category--from 1979 to 1982, bars indicate ±1.0 S.D.

new terminals that regain the height lost by the end of the third growing season. Others do not regain the growth lost because poor vigor and/or repeated terminal mortality keeps the tree suppressed.

Tree mortality was the most drastic effect of saperda. This mortality after the first year was due in part to repeated attacks by the poplar-gall saperda combined with poor tree growth. After the third year tree mortality was not observed from saperda, even though the total number of galls increased. During the third growing season 70 percent of the galls observed were located on lateral branches, and these had no direct effect on tree height.

The position and pattern of galls on hybrid poplars are related to tree size as well as proximity to infested trees. Plantations established with whips are vulnerable to attack during the first growing season while those established with hardwood cuttings are not vulnerable to attack until the trees reach sufficient size in the second growing season. The first attacks are on the main stem due to the small diameters of the lateral branches; but as the tree grows, the position of new attacks occurs higher up on the main stem (Figure 6).

These data suggest that the poplar-gall saperda is not a threat to young trees up to the attack level of four stem

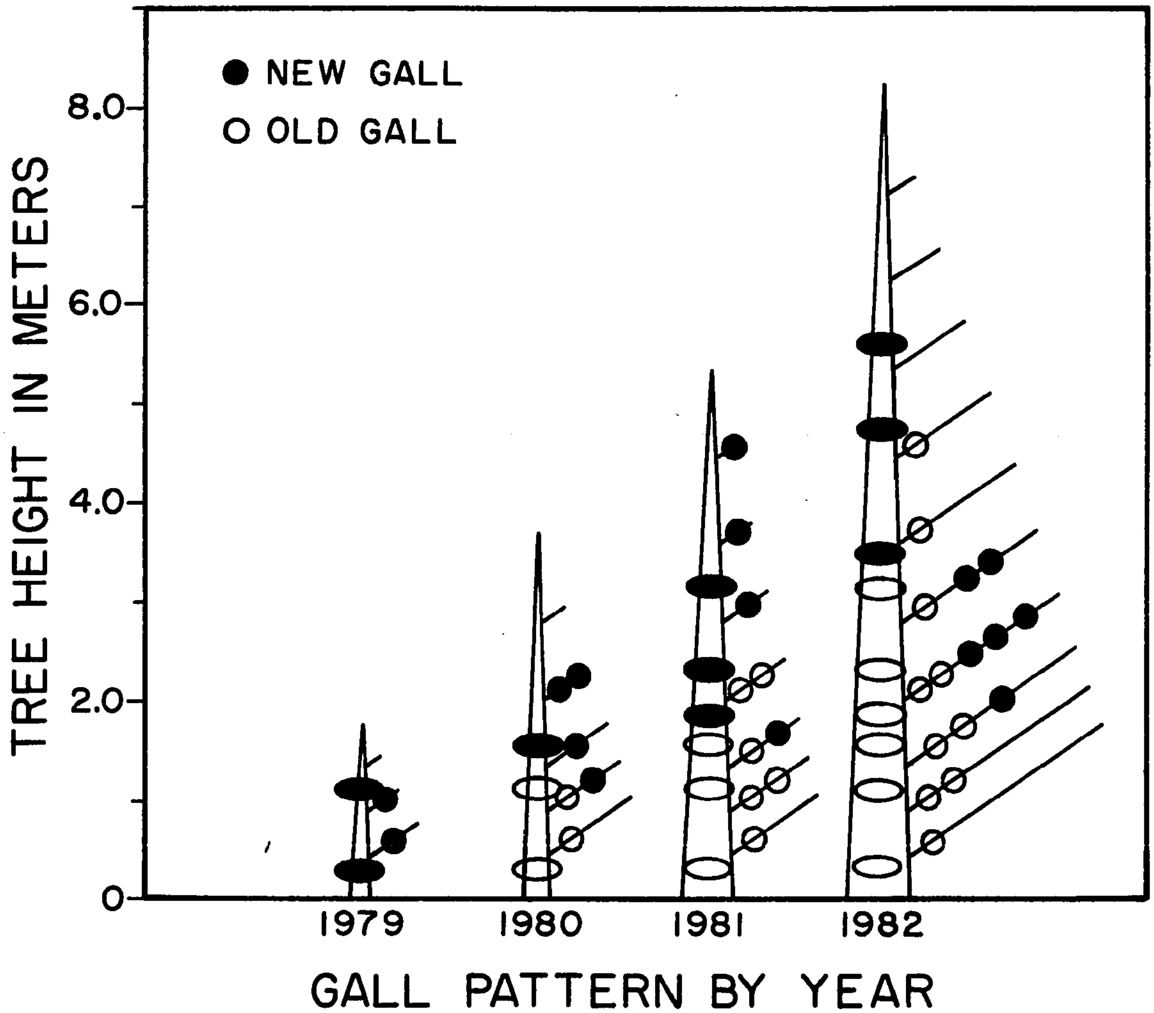

Figure 6. Pattern of attacks by the poplar-gall saperda on the stem and lateral branches by year.

galls per tree during the first two growing seasons. Mortality of 4 percent after 4 years is no more than might be expected from most other causes and is certainly a minor concern for biomass production. When I compared the impact of the saperda to the impact of other biological organisms, I observed a total impact of 15 percent (tree mortality plus top killed) and 18 percent, respectively (Table 2). Although this insect has not been proven to be a destructive pest in this study, further research is needed with many different *Populus* clones under variable growing conditions before its real impact can be determined.

Tarnished Plant Bug

Brief Life History

The tarnished plant bug (TPB) nymphs and adults feed on the sap of young poplar shoots throughout the growing season. The adults become active very early in the spring and feed on the terminal shoots and fruits of fruit trees (Metcalf *et al*. 1962) The egg is deposited in the stem, the petiole, the midrib of leaves, into a bud, or among the florets of the flower head of herbaceous weeds, vegetables and flowers (Metcalf *et al*. 1962). Sapio *et al*. (1982) observed eggs embedded in the bark of poplar shoots. The nymphs hatch in about 10 days depending on temperature and immediately begin feeding on plant sap. They grow rapidly, molting five times.

Damage

Feeding damage by this bug is usually limited to young shoots in the nursery and young plantations. The newly hatched nymphs feed by inter- and intra-cellular stylet penetration, and during feeding they secrete saliva that affects tissue development (Tingey and Pillemer 1977). The combination of feeding and salivary secretion causes the stem to develop a split-stem lesion at the point of attack. If the main stem is severely damaged and breaks, the tree may produce mutiple shoots without a dominant leader. Less severely damaged trees show signs of broken laterals and reduced growth.

Methods and Materials

In the spring of 1983, three rooting beds in the PCA nursery were planted with 18-cm hardwood cuttings cut the previous fall from the stool beds of 21 different hybrid *Populus* clones (see Table 3 for acquisition numbers and clonal parentages). Single, and occasionally double or triple, shoots (whips) grew from these cuttings. By fall, the whips were 0.3 - 1.5 m tall and ready for lifting as rooted stock.

Table 3. Susceptibility of 21 *Populus* clones to tarnished plant bug (TPB) feeding injury, PCA clonal nursery, Freesoil, MI, 1983

Clone	Parentage	Number lesions (200 trees)	Percent trees with lesions
'WIS 5'	*Populus* x *euramericana* 'Wisconsin 5'	311	82.0
DN-34	*P.* x *euramericana* 'Eugenei'[c]	96	37.5
FRS-2[a]	- - -	66	25.0
DN-31	*P.* x *euramericana* 'Negrito de Granada'	44	22.0
DN-55	*P.* x *euramericana*	50	21.5
DN-21	*P.* x *euramericana* 'Jacometti'	38	17.0
NE-308	*P. nigra* var. *charkowiensis* x *P. nigra* 'Incrassata'	37	16.5
DN-1	*P.* x *euramericana* 'Allenstein'	22	11.0
I45/51	*P.* x *euramericana* 'I45/51'	32	10.0
RAV	*P.* x *euramericana* 'Raverdeau'	11	5.5
DN-34[b]	*P.* x *euramericana* 'Eugenei'[c]	8	4.0
NC-5258	*Populus* sp.	6	3.0

Table 3 continued

Clone	Parentage	Number lesions (200 trees)	Percent trees with lesions
DN-9	*P.* x *euramericana* 'Lons'	5	2.5
DN-30	*P.* x *euramericana* 'Canada Blanc'	5	2.5
FRS-1[a]	- - -	4	2.0
NC-238	*P. deltoides* x *P. nigra* 'Volga'	3	1.5
NE-19	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*	3	1.5
NE-20	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*	2	1.0
DN-18	*P.* x *euramericana* 'Tardif de Champagne'	2	1.0
DN-22	*P.* x *euramericana*	2	1.0
NE-359	*P. deltoides* x *P. nigra* var. *caudina*	1	0.5

[a]Unidentified clones from Fry Nursery.

[b]Cuttings taken from a large windbreak on Milarch Road near Manistee, MI.

[c]Commonly called Imperial Carolina poplar or Carolina poplar.

On 28 and 31 October, 1983, TPB lesions were counted on 200 whips of each clone just before lifting. Whips were examined in groups of 30 - 40, and then 5 - 15 m of the row were skipped before counting again so that most of a row was covered. Whips shorter than 0.3 m were not examined because these normally are culled during sorting. Some lesions were examined in detail and characterized by size, form, and strength of the stem at the lesion.

After the most heavily injured clone had been lifted, the rooted whips of that clone were sorted into three classes as follows: 1. suitable for fall planting; 2. suitable for spring planting; and 3. unsuitable (culls). Sorting was based on requirements for fall and spring stock as well as on TPB injury. Fall planting stock differs from spring stock by size and treatment. Fall stock is graded and 0.6 m tall, and larger trees are field planted immediately after lifting from the nursery. Spring stock (0.6 - 1.5 m tall) is stored over winter in bundles in healing beds; just before planting, the tops of the whips are removed above 0.6 m.

The lesion's size and location on the whip were the criteria used in sorting the fall- and spring-rooted stock. The intensive forestry manager at PCA would not accept any stock for outplanting with large lesions because of the good chance of breakage. However, he accepted all small healed-over lesions. Because fall stock is planted with tops intact, all whips chosen for fall stock with large lesions above the 0.6-m level automatically became spring stock. The intensive forestry manager would accept all spring stock with small lesions anywhere on the stem and large lesions only above 0.6 m because the stock is trimmed above that level.

Stock in the nursery stool beds was also injured by the TPB in 1983. When the stool bed whips were cut, 100 - 300 of them were selected from three clones, sawed into 18- and 33-cm cuttings, and sorted into acceptable or cull classes. The three clones sampled were 'Wisconsin 5', Imperial Carolina Poplar (DN-34), and Raverdeau.

Results and Discussion

The TPB feeds all over some clones of young Populus as young lesions occurred along the length of the .3- to 1-m-tall whips. Short whips usually are lesioned more on the upper half. Depending on the duration of feeding and perhaps the ability of the tree to withstand the enzymatic activity of the TPB saliva, lesion formation and its consequences for the tree vary considerably. Whatever the cause, at the end of the growing season some lesions remain small and nearly imperceptible except for slight swelling. Lesions that are swollen enough for easy detection measure about 1.5 cm long with a small slit or scar on the surface. Internally these lesions produce only minor necrosis in the attending xylem, which varies little from the uninjured stem. With the exception of their possible role as an infection court, small healed-over lesions do not affect the strength of the whip.

Large lesions are more extensively necrotic, and structurally weaker. One type of lesion is usually 1.5 - 2.0 cm long and swollen into an ovoid gall. Outwardly the gall has ribs and/or slits and is heavily calloused. Internally the gall is hollow or honeycombed and any remaining xylem is generally necrotic and punky. Another type of lesion is flattened into an elongate flared area of blasted tissue, which resembles the hood of a cobra. It is the largest type of lesion--often over 3.0 cm and sometimes as much as 5.0 cm long and over 1.0 cm wide. Slits through the tissue may occur in the flattened area. In the cross section, the lesioned area is mostly a veneer of necrotic xylem backed by bark and callous tissue. Often the stem bends over at the lesion, sometimes to a right angle. The stem above such lesions sometimes dies; often it breaks.

Although 21 clones in this study were injured by the TPB, incidence of injury differed widely among the clones, suggesting broad tolerance by _Populus_ (Table 3). Location in the nursery rooting beds apparently did not affect the degree of injury because the heaviest and lightest attacked clones occurred side by side. 'Wisconsin 5' was by far the most heavily lesioned clone; it had 311 lesions on the 200 sample trees or 1.6 per tree (range 0 to 6), and 82.0 percent of the trees had at least one lesion. Four other clones (DN-34, FRS-2, DN-31, and DN-55) were moderately injured, with 21.5 to 37.5 percent of the trees lesioned. About half of the clones were less than 10 percent affected while NE-359 had only 1 lesion. Imperial Carolina poplar (DN-34) stock from two sources showed both moderate and light incidence of injury. The most injured Carolina poplar stock was the purchased source, the other was derived from cuttings from a large windbreak on Milarch Road near Manistee, MI. The purchased stock had 37.5 percent lesions, but only 4 percent of the Milarch Road whips had lesions. Two FRS clones (FRS-1 and FRS-2) also showed wide differences in lesion incidence. These two unidentified clones were pulled out of mixed stock shipped from the Fry Nursery in Pennsylvania. Most clones in the study were of _P._ x _euramericana_ parentage and showed a wide range of lesioning.

The original TPB study on _Populus_ from Rhinelander, WI, provided the only other source of host-resistance data available to date for comparison to this study (Sapio *et al*. 1982), but there are only four clones in common between the two studies: Imperial Carolina poplar, 'Wisconsin 5', DN-30, and NC-5258. In Wisconsin all four of these clones were injured lightly (3 percent) or not at all by the TPB. Yet the potential for moderate or heavy injury was there because 43 percent of the trees of clone NE-298 (*P. nigra* var. *betulifolia* x *P. trichocarpa*) had lesion injury. 'Wisconsin 5' and Carolina poplar were the two clones most heavily lesioned at PCA in contrast to the light attacks in Wisconsin. Clones DN-30 and NC-5258 differed little between the two locations.

The reasons for the locational differences in TPB injury are unclear. The study plots in Wisconsin had more weeds nearby, and that may have been important. Sapio *et al*. (1982) found some differences in resistance or tolerance of *Populus* to the TPB, but concluded they were only partially clonal and tempered by the presence of other food sources including weeds. The PCA nursery was particularly clean of weeds. Diligent searching uncovered only an occasional small patch of quackgrass (*Agropyron repans* (L.) Beauv.) or wild carrot (*Dacus carota* L.). *Populus* appears to be more vulnerable to attack in areas free from vegetation (Sapio *et al*. 1982), but this does not fully explain the great differences in attack of clones planted side by side in rows only 0.7 to 1 m apart.

The rise in TPB population between 1982 and 1983 at the PCA nursery may have been due in part to a change in utilization of land surrounding the nursery. In 1983 fields on four sides were planted to corn, a host of the TPB. Before then, corn had never been planted entirely around the nursery and the TPB was not a problem. Also, the record mild winter of 1982-83 may have contributed to adult overwintering survival and population increase. The insect has three generations per year in Michigan and an increase in survival could increase the size of the second and third generations, which seem to be the ones that attack Populus. The locations of the lesions (i.e., the lack of lesions in the first 0.3 m) suggest that the first generation causes little or no injury to Populus.

The results from sorting the rooted nursery stock for fall and spring outplanting indicated that few whips were rejected in the lightly infested stock, but culls became more numerous as the number of lesions increased. Rejections were most numerous with 'Wisconsin 5' being the most injured clone. Sorting of 500 whips of 'Wisconsin 5' resulted in 100 whips suitable for fall stock, 100 whips for spring stock, and 300 culls. By these standards

'Wisconsin 5', which was 82 percent lesioned, lost 60 percent of the rooted whips as culls--a totally unsatisfactory level. To alleviate this problem, the intensive forestry manager lowered the standard for the spring stock of this clone by trimming the whips back to 0.3 m instead of 0.6 m, thus accepting the spring stock with any size lesions above the 0.3 m mark. In fact, most of the lesions were on the stem between 0.3 and 0.6 m above the original cutting. Sorting of 260 'Wisconsin 5' whips using the new standard resulted in 49 whips suitable for fall stock, 201 whips for spring stock, and 10 culls. The 4 percent cull was fully satisfactory, so the new standard was used on 'Wisconsin 5' and the other heavily lesioned clone (DN-34) to reduce the culls, essentially eliminating the TPB as a problem on the rooted planting stock. Clones with few lesions were sorted by the old standard because culls remained below 10 percent--the level chosen for changing the method.

Stool-bed whips produced about six to seven 18- and 33-cm cuttings. Sorting yielded some culls for each of the three clones sampled (Table 4). In 'Wisconsin 5', over 18 percent of the 18-cm and almost 12 percent of 33-cm cuttings, or about 15 percent of both were culls. Carolina poplar and Raverdeau cutting losses to TPB injury were 3.2

Table 4. Hardwood stool bed cuttings acceptable for planting and culled because of lesions caused by tarnished plant bug for three *Populus* clones from the PCA nursery

		18-cm cuttings		33-cm cuttings		Both	
Clone	Cuttings per 100 whips	Accept	Cull	Accept	Cull	Accept	Cull
	Number	- - - - - - - - - - Percent	- - - - - - - - - -				
'Wisconsin 5'	635	81.9	18.1	88.4	11.6	85.4	14.6
Carolina Poplar	653	96.2	3.8	97.8	2.2	96.8	3.2
'Raverdeau'	689	97.4	2.6	91.7	8.3	95.5	4.5

and 4.5 percent. If 10 percent is set as the maximum allowable cull, then injury to 'Wisconsin 5' would be unacceptable and would have to be controlled. Degree of attack was not tallied in the stool beds, but it was obvious that injury to clones like 'Wisconsin 5' was far less than in the rooted stock. Stool-bed whips, which grow in clumps on a large root stock, are generally larger, more vigorous, and more numerous than rooted stock, which grows as one or two whips from a cutting. This may deter TPB feeding or may dilute the amount of feeding.

When Populus nursery stock is scarce, accepting smaller rooted stock from heavily infested TPB could at least partially alleviate the problem when only a few clones are injured. The same could be done for the hardwood cuttings. Cuttings are chosen at 33 and 18 cm to provide the largest stock that can be field planted by machine and nursery planted by hand, respectively. Larger stock also assures better survival. In other circumstances, the TPB may need to be controlled.

Willow Shoot Sawfly

Brief Life History

The female willow shoot sawfly girdles the stem of newly developing shoots with a series of punctures made by her saw-like ovipositor (Riley 1888). The egg is deposited below the girdle area. Larvae hatch in 7 to 12 days depending on local temperature, and immediately tunnel toward the tip of the girdle, then turn, and tunnel downward for about 15 to 36 cm. Occasionally they tunnel the entire shoot and into the roots. The mature larva prepares for adult emergence by chewing a hole nearly through the bark; then it enlarges the gallery and constructs a cocoon-like structure and pupates (Solomon and Randall 1978).

Damage

Shoots attacked by the sawfly wilt from the girdling of the shoot by the sawfly's multiple punctures of its ovipositor. Wilted shoots, which resemble a shepherd's crook, are the first sign of attack. The larvae tunnel in and kill the tender shoots as they extend their galleries downward. Shoot mortality results in branching and formation of crooked or forked stems. In the nursery both number and quality of cuttings are reduced. In young plantations, heavily damaged trees may become bushy or forked, with little economic value, while lightly damaged trees may recover dominance.

Methods and Materials

On July 9, 1981, three plots were established in the nursery to study the willow shoot sawfly. Each study plot had a 3-m buffer on the west side and a two-row buffer on the north and south sides. The plot consisted of 11 rows. The clones used in this study are listed in Table 5. On July 9, 1981, shoot height was measured and then the level of insect infestation was recorded each week for 4 consecutive weeks.

On October 28, 1981, shoots were harvested, measured, and cut into 25 cm lengths and stored in cold storage at $\pm 2°C$ for planting during the spring of 1982. On May 19, 1982, cuttings were taken from cold storage and hand planted in the nursery at a 4.0-cm x 0.9-m spacing. Plantings were then inspected once each week for the first 4 weeks to determine if sawfly damage could be related to shoot survival or performance. Thereafter shoots were examined at 8 and 12 weeks after planting. Also, on May 19, 1982, five stools within the 1981 study plot were dug and examined for incidence of the willow shoot sawfly. Fifteen additional stools were randomly selected and caged to determine if adults were emerging from stools left after fall harvest.

In 1983, poplar shoots growing adjacent to a pile of discarded cull whips and cuttings were sampled to determine the incidence of attack. Shoots were examined twice daily for 4 weeks (morning and afternoon); attacked shoots were counted and rated for level of damage.

Results and Discussion

The willow shoot sawfly infested *Populus* shoots of various clones within the nursery from 1981 to 1983. These shoots varied in height from about 0.3 m to 1.5 m. Tips girdled by the female started to wilt within 5 to 10 minutes, depending on shoot vigor and weather. Shoots were also attacked at various distances from the tip, with no distinct pattern.

Sawfly damage was heaviest on shoots that were less than 25 cm long. These shoots were usually completely killed by larval tunneling. In many cases larva would tunnel the entire length of the shoot and into the stool. Some larvae would die after tunneling the length of the shoot while others would be trapped and killed by rapidly growing shoots.

Osgood (1962) reported only one generation per year in Minnesota. In Michigan it appears that the sawfly has two or more generations per year, but this conclusion is based only on periodic observations during the growing season. The first shoot damage was observed during late spring or early summer, and the second level of attack was observed in mid-to-late summer. Peak attack appeared to be in late July and early August.

The willow shoot sawfly evaluation of 17 Populus clones in the nursery indicated that injury differed widely among clones, suggesting a broad tolerance (Table 5). The location of clones, however, seemed to affect the degree of injury; clones most heavily attacked in 1981-1982 were at the west end of the nursery adjacent to a mature Norway spruce (Picea abies (L.) Karst) windbreak. These trees shaded shoots in the afternoon, allowing the shoots to remain tender for a longer period of time. The windbreak also offered protection for the adults when normal field operations like cultivation and/or irrigation were performed. DN-55 was the most heavily attacked clone with 49 of the 88 shoots (56 percent) examined infested by the sawfly. Five other clones (5258, DN-9, WIS-5, DN-34, DN-28) were moderately infested with 23 to 29 percent of the shoots attacked. About half of the clones had 3 to 18 percent of their shoots attacked. Three other clones (DN-17, DN-18, DN-19) were free of attacks. The number of attacks by the willow-shoot sawfly was nil on clones in areas that were exposed to full sun throughout the day.

Table 5. The impact of the willow shoot sawfly on 16 *Populus* clones at the PCA nursery, 1981

Clones	Parentage	Shoots		
		Number examined	Number attacked	Percent attacked
DN-17	*P.* x *euramericana* 'Robusta'	24	0	0
DN-18	*P.* x *euramericana* 'Tardif de champagne'	10	0	0
DN-19	*P.* x *euramericana* 'Blanc du Poitou'	26	0	0
DN-21	*P.* x *euramericana* 'Jacometti'	30	1	3
DN-22	*P.* x *euramericana* 'I-262'	52	3	6
NE-308	*P.* *nigra* var. *charkowiensis* x *P.* *nigra* 'Incrassata'	33	2	6
DN-31	*P.* x *euramericana* 'Negrito de Granada'	73	9	12
DN-1	*P.* x *euramericana* 'Allenstein'	31	4	13
I45/51	*P.* x *euramericana*	27	4	15
NE-238	*P.* *deltoides* x *P.* *nigra* 'Volga'	22	4	18
DN-28	*P.* x *euramericana* 'Ostia'	26	6	23
DN-34	*P.* x *euramericana* 'Eugenei'	96	26	27
WIS-5	*P.* x *euramericana* 'Wisconsin-5'	26	37	29
DN-9	*P.* x *euramericana* 'Lons'	03	30	29
NC5258	*Populus* *spp.*	28	8	29
DN-55	*P.* x *euramericana*	88	49	56

In 1983 the most heavily attacked area in the nursery was adjacent to a pile of discarded hybrid poplar planting material. Examination indicated that about 10 percent of it was infested by the willow shoot sawfly. Ten stools with multiple shoots growing in full sun adjacent to the infested material were heavily attacked by the sawfly from mid-June to mid-July. Many of the shoots were attacked more than once at different levels on the shoot. The number of new shoots attacked dropped to zero once the pile of infested material was burned. Thus, the infested pile served as a source of infestation for healthy trees by providing protection for the adults.

Septoria Leaf Spots and Cankers

Brief Life History

Septoria is a pathogenic fungus that infects native and hybrid poplars throughout North America (Bier 1939, Thompson 1941, Waterman 1954). The fungus produces both leaf spots and cankers on trees of various ages and sizes. The pathogen overwinters on fallen infected leaves and in branch and stem cankers (Thompson 1941, Palmer *et al*. 1980). In spring, ascospores of the perfect stage, *Mycosphaerella populorum* G. E. Thomp., form perithecia on fallen leaves; conidia from pycnidia in cankers are released during wet weather. These spores are carried by rainsplash and/or wind, to leaves, stems, and branches where infection occurs. These new infection centers increase rapidly under favorable moisture conditions.

Septoria leaf spots can occur on both sides of the leaf surface. Infested spots range from white to dark brown but are usually darker on the upper leaf surface. Individual spots range from 1 to 15 mm in diameter (Schipper 1976); but may coalesce to form large necrotic areas that cover half the leaf surface (Filer et al. 1971). These leaf spots vary according to leaf texture and host tree. Infected spots are usually globose or depressed and embedded in the leaf tissue below the epidermis.

Septoria cankers are usually found on the main stem and branches within 1.5 m of the ground. Cankers can serve as entry points for Phomopsis, Cytosporia, Dothichiza and other secondary canker fungi (Palmer et al. 1980).

Damage

Leaves infected with septoria drop to the ground and serve as an inoculum source or remain on the tree and infect the young shoots. These infected shoots become blackened and slightly depressed forming a small canker. Small shoots are girdled by the canker and break over.

Cankers on the main stem cause stem breakage, reduced growth or kill the tree. Heavily infected trees break at the point of injury, causing growth loss and tree deformity. Several basal cankers can kill the tree by girdling.

Methods and Materials

This study was made from 1979 to 1982 in the PCA nursery clonal beds and in the *Populus* mixed clonal plantation adjacent to the nursery. The 40-clone plantation of about 2,400 trees was established in 1976 at 3 x 3 m spacing from rooted cuttings. In the fall of 1980, the trees were cut either flush to the ground or with stumps up to 15 cm high.

In September 1981, 2,529 stump sprouts were examined for septoria cankers in a block of 75 trees. I counted cankers, estimated their severity, recorded their location on the sprouts, and determined the site of infection. Pearson's chi-square goodness-of-fit test was used to determine the level of significance between expected and observed data for each sample element.

In 1979, 57 different poplar clones were growing in the nursery in stool beds spaced at 0.9 x 0.3 m and at 0.9 x 0.7 cm. Weeds were regularly controlled with herbicides and cultivation. Nursery beds were irrigated as needed by overhead or trickle irrigation.

Trees in the nursery were examined several times during the summers of 1979 and 1980 for prevalence of septoria cankers and leaf spots. Fifty whips were examined from each clone each year and evaluated for susceptiblity or tolerance. Clones cankered or heavily infected with leaf spots were rogued from the nursery in the fall of 1980.

Results and Discussion

After the 1976 plantation coppiced, there was an average of 34 sprouts per stump (range 2-84); 52 percent of them were infected in the fall of 1981. All but one of the 75 stumps examined had at least one cankered sprout. Septoria canker was more prevalent on lower stems. Numbers of cankers were inversely related to three heights (<0.3 m, 0.31 - 0.6 m, >0.6 m) and significantly differed from expected using chi^2 ($P<0.001$). The total number of cankers varied from 1,404 (70 percent) to 454 (23 percent) to 148 (7 percent) (Table 6). At the lower height (<0.31 m), buds and leaf petioles were the most prevalent sites for canker infection; each had twice the number of cankers as the stem or branch sites (significant chi^2 at $P = 0.001$, Table 7). Infection was equal at the higher two heights.

Septoria infection in nursery stock was a major problem at the nursery from 1979-80. Nursery stool beds are injured more by septoria because they are more closely spaced and

Table 6. Pearson's goodness-of-fit test used for comparing the significance of septoria canker at various heights and positions on poplar sprouts

	Location of cankers				
Height in meters	Leaf petioles	Bud	Stem	Branch	Total
0.0-0.3	(O) 455*	501*	262	186	1,404
	(E) 480	480	259	184	
0.31-0.6	(O) 170	145	80	59	454
	(E) 155	155	83	59	
	(O) 61	40	29	18	148
>0.6	(E) 50	50	27	19	
Total	686	686	371	263	2006

* = Significant difference at chi^2, $P<0.05$.

O = Observed; E = Expected

Table 7. Pearson's goodness-of-fit test used to determine the significance of septoria cankers at the various positions on trees when height is less than 0.31 m

	Location of cankers					
Height in meters	Leaf petiole	Bud	Stem	Base	Branch	Total
0.0-0.3	(O) 455*	501*	262	299	186	1703
	(E) (340)	(340)	(340)	(340)	(340)	

* = Significant difference at chi^2, P<0.001.

O = Observed; E= Expected

thus retain higher moisture. Overhead irrigation probably further increased infection. Nearly two-fifths of the clones in the nursery were heavily infected with septoria. This problem has been reduced by the removal of highly susceptible clones with *P. maximowiczii*, *P. laurifolia*, and *P. trichocarpa* parentage (Table 8). Clones that exhibited disease resistance and good growth and form were retained in the nursey for production of planting stock (Table 9). A program to screen all clones for resistance to septoria is underway.

Septoria infection was a major problem in several of PCA's hybrid poplar plantations. Several plantations were severely damaged by septoria cankers on the main stem and lateral branches. The Lloyd plantation was the worst with over 80 percent of the trees infected.

Because the plantation was established with mixed hybrid cuttings, identification to specific clones was impractical. However, these clones were easily identified as NE-235, NE-308, and NE-353. Clone NE-235 was the most severely damaged. Over half of the infected trees had either tops broken out or were killed to the base by septoria. NE-308 and NE-353 were infected with septoria canker, but the level of infection was low. However, the level of infection in these clones is expected to increase as the level of

Table 8. *Populus* clones susceptible to *Septoria musiva* in the PCA nursery

Clone	Parentage (female:male)
NE-205	*Populus deltoides* x *P. trichocarpa*
NE-206	*P. deltoides* x *P. trichocarpa*
NE-207	*P. deltoides* x *P. trichocarpa*
NE-346	*P. deltoides* x *P. trichocarpa*
NE-252	*P. deltoides* var. *angulata* x *P. trichocarpa*
NE-374	*P. deltoides* var. *angulata* x *P. trichocarpa*
NE-373	*P. deltoides* var. *angulata* x *P. trichocarpa*
NE-264	*P. deltoides* var. *angulata* x *P. nigra* 'Volga'
NE-225	*P. deltoides* x *P. nigra* var. *caudina*
NE-344	*P. deltoides* x. *P. grandidentata*
NE-388	*P. maximowiczii* x *P. trichocarpa*
NE-41	*P. maximowiczii* x *P. trichocarpa* 'Androscoggin'
NE-47	*P. maximowiczii* x (*P.* X *berolinensis*)
NE-51	*P. maximowiczii* x *P. nigra* var. *plantierensis*
NE-1	*P. nigra* x *P. laurifolia* 'Strathglass'
NE-300	*P. nigra* var. *betulifolia* x *P. trichocarpa*
NE-299	*P. nigra* var. *betulifolia* x *P. trichocarpa*
NE-387	*P.* 'Candicans' x (*P.* x *berolinensis*)
NE-386	*P.* 'Candicans' x (*P.* x *berolinensis*)

Table 9. Populus clones with apparent resistance to Septoria musiva in the PCA nursery

Clone number	Parentage (female:male)
DN-34	Populus x euramericana 'Eugenei'
DN-30	P. x euramericana 'Canada Blanc'
DN-28[1]/	P. x euramericana 'Ostia'
DN-5	P. x euramericana 'Gelrica'
I-45/51	P. x euramericana 'I 45/51'
WIS-5	P. x euramericana 'Wisconsin #5'
DN-21	P. x euramericana 'Jacometti'
DN-9	P. x euramericana 'Lons'
DN-31	P. x euramericana 'Negrito de Granada'
DN-55	P. x euramericana 'DN-55'
DN-17	P. x euramericana 'Robusta'
DN-18	P. x euramericana 'Tardif de Champagne'
DN-1	P. x euramericana 'Allenstein'
DN-3	P. x euramericana 'Dolomiten'
RAV	P. x euramericana 'Raverdeau'
NE-238[1]/	P. deltoides x P. nigra 'Volga'
NE-366[1]/	P. x deltoides x. P. nigra var. caudina
NE-353[1]/	P. x deltoides x. P. nigra var. caudina
NE-367[1]/	P. x deltoides x. P. nigra var. caudina
NE-278[1]/	P. x nigra x (P. x euramericana 'Eugenei')
NE-308[1]/	P. nigra var. charkowiensis x. P. nigra 'Incrassata'

Table 9 continued

Clone number	Parentage (female:male)
NE-316[1/]	P. nigra var. charkowiensis x (P. x euramericana 'Robusta')
NE-318[1/]	P. nigra var. charkowiensis x P. deltoides
NE-19[1/]	P. nigra var. charkowiensis x P. nigra var. caudina
NE-20[1/]	P. nigra var. charkowiensis x P. nigra var. caudina

[1/] Trees of these clones are infected with Septoria canker in plantations in Minnesota, Iowa, and/or Michigan (Ostry, unpublished data).

inoculum increases within the plantation. An overabundance of this fungus appears to reduce the tolerance of all clones to septoria infection.

Septoria canker was also a major problem on trees in Logan 24. The trees most severely affected were those with P. maximowiczii, P. laurifolia, and P. trichocarpa parentage, which I expected. However, NE-19 and NE-20, two of the clones that had shown a high level of tolerance to both septoria canker and leaf spots, were moderately infected with cankers in 1982. Before 1982, these clones were considered among the most pest tolerant of clones, and they were being suggested along with DN-34, NE-353, and NE-308 as the best clones for planting in the Lake States. Since these results suggest that NE-19 and NE-20 might lose their level of tolerance after 5 years, all plantations 5 years or older containing these clones should be monitored for increases in septoria infection.

Septoria can be a problem in stump culture management as indicated by the heavy infection of a highly susceptible coppiced planting adjacent to the nursery. Densely spaced sprouts encourage septoria infection by trapping infected leaves and retaining a moist micro-environment ideal for infection. Infected leaf debris around the stumps also contributed to pathogen retention, spread, and disease severity.

Bier (1939) concluded that *P. deltoides* was somewhat resistant to canker formation, and Waterman (1954) noted native cottonwood had little septoria and appeared highly resistant. Filer *et al.* (1971), however, found septoria on *P. deltoides* nursery stock in Mississippi. Additional research is needed to clarify the question of its susceptibility in the north-central United States.

All the *P. maximowiczii* crosses were heavily infected in the nursery. This group has been highly susceptible in cottonwood inoculation tests, and cankers also have been found on this species in the eastern states (Waterman 1954). However, these trees maintained good growth and it was thought that their vigor was sufficient to offset the effects of the disease. Although rarely injured, they were thought to be a source of abundant inoculum (Waterman 1954).

P. trichocarpa appeared as the male parent in 11 of the 19 highly susceptible crosses at PCA and in none of the resistant clones, indicating that *P. trichocarpa* may contribute to clonal vulnerability of *S. musiva*. *P. trichocarpa* crosses (as the male parent) have been rated more susceptible to septoria than *P. deltoides* (as the female parent) (Waterman 1954). Six of our *P. deltoides* crosses were ones with *P. trichocarpa* (NE-205, NE-206, NE-207, NE-346, NE-374, NE-373) and were among the most heavily cankered.

Septoria canker and leaf spot is the most damaging disease of hybrid poplars in the North Central Region as well as throughout the native or hybrid range of Populus and, unless managed, can limit the usefulness of susceptible clones. Nursery stock and plantation coppice are infected by spores from infected leaf debris in early spring. Removing this debris is a recommended control strategy. However, local screening of clones for resistance and planting these clones is the most promising long term control strategy in areas where septoria is known to be a problem. Until this screening is complete, land managers should be aware of the potential hazard from septoria, if highly susceptible clones are planted.

Marssonina Leaf Spot

Brief Life History

Marssonina leaf spot occurs as small reddish-brown to purple discolorations on the upper and lower leaf surfaces. The spots darken with age and develop into circular lesions about 1 mm across. During humid weather the macroconidia from the acervuli are released and disseminated by rainsplash and wind. The fungus overwinters on fallen infected leaves and in spring forms apothecia, the perfect stage of the pathogen. When the fungus overwinters on twigs, it produces conidiaspores and allows the fungus to complete its life cycle without the perfect stage.

Damage

The fungus attacks both the foliage and woody portions of the tree. Attacks on the foliage can result in premature yellowing and leaf dropping. Consecutive attacks over several years can lead to retarded growth, reduced tree vigor, and die back. Spores landing on lateral branches and petioles produce branch and petiole lesions that can serve as points of entry for Cytospora and Dothichiza cankers. These lesions can also cause premature defoliation and branch breakage.

Results and Discussion

Marssonina fungal infection was present at some level on all the poplar clones I examined from 1980 to 1983. The level of infection on trees within clones ranged from none to severe, depending on plantation location and time of year.

Trees located in plantations adjacent to old stands infected with marssonina were usually attacked during the first growing season. The level of infection varied from a trace to light. Clones planted in open fields bordered by uninfected trees were usually free of infection during the first growing season. Also, trees growing on plantations previously infected by marssonina had a higher incidence of leaf spots than trees in previously uninfected plots.

Hubbes (1977) observed that occasional attacks by the fungus caused annual increment losses. During years of consecutive attacks, he reported drastic reduction in tree vigor and annual increment. He also reported that reduced vigor can cause lower branches to die back and, in some cases, can cause total tree mortality. Butin and Zycha (1973) reported that low frost resistance or attacks by Cytospora canker, Dothichiza canker, root rots, and decays were associated with the fungus. From their study of marssonina infections of eastern cottonwood in Illinois and along the course of the Mississippi River from Mississippi to Iowa, Jokela et al. (1976) concluded that marssoninia leaf spot is a great threat to intensively managed cottonwood. They also observed clonal resistance to the fungus. Hubbes (1977) reported a number of poplar clones resistant to marssonina leaf spots. However, in this study, no clones were without some fungus, and some clones appeared to be more susceptible than others.

Poplar Leaf Rust

Brief Life Cycle

The poplar leaf rust infects both poplar and larch (*Larix spp*). The rust overwinters as teliospores on fallen leaves of poplar and germinates in spring to produce basidiospores at the time of larch needle elongation (Ziller 1965). Infection on current season needles appears in 1 to 2 weeks after the inoculation by basidiospores (Weir and Hubert 1978; Ziller 1965, 1974). These needles are only susceptible to infection for a very short time because the aeciospores found on infected needles can infect poplar but cannot reinfect other larch (Widin and Schipper 1976). Poplar leaves infected by aeciospores produce uredospores, which can reinfect poplar leaves throughout the summer (Shain 1976, Taris 1968, Toole 1967). Germinating uredospores enter the poplar leaf through the stomata (Chiba 1966).

Damage

Poplar leaf rust on poplars is confined to the underside of leaves. The fungus under favourable weather conditions can reach epidemic proportions. Severely infected leaves cause premature defoliation, which causes growth loss and increases the tree's susceptibility to other diseases (Hubbes 1977).

Methods and Materials

The poplar leaf rust was studied in 1979 and 1980 at the PCA nursery. The plot contained five different _P._ x _jackii_ clones (JAC-7, DBJ-2-1, LJ-14, LUJ-7, DBJ-2-2) and two NE clones (NE-19, NE-20). Trees in these clones were examined once each week during the summer until the infection was detected. Once leaves were infected, examination of the infected area was made at 2- to 3-day intervals for the duration of the growing season or until the trees were defoliated to obtain a severity rating (0, trace, light, moderate, heavy, severe).

In the PCA hybrid poplar clonal trials, trees were examined for poplar leaf rust and rated as to severity (trace, light, medium, heavy, severe).

Results and Discussion

The first leaf rust spots were observed in the nursery in mid- to late July in 1979 and 1980. Infection and defoliation were restricted to the _P._ x _jackii_ clones. NE-19 and NE-20 had only a trace of melampsora on a few leaves. By mid-August, infected whips were 50 percent defoliated, and by mid-September, infected whips were about 99 percent defoliated.

In the clonal trials, poplar leaf rust was not observed to be a problem on clones without _P._ x _jackii_ parentage. Several other clones, however, did occasionally have infection levels that ranged from trace to medium.

Because melampsora is a foliage disease that occurs late during the growing season (late July to mid-September), it is difficult to rate its impact on tree performance. However, clones with _P._ x _jackii_ parentage were rogued from the nursery because of severe defoliation for 2 consecutive years and in an effort to reduce the level of inoculum in the stool beds.

The poplar leaf rust was of little importance in the clonal trials due to low levels of infection on all clones except clones with _P._ x _jackii_ parentage. None of the trees were defoliated nor were there signs of growth loss when compared with adjacent trees. However, Schipper and Dawson (1974) observed this disease to have the potential to severely reduce biomass yields. In Wisconsin, Minnesota, and Iowa, Widin and Schipper (1981) observed up to 42 percent reduced wood volume of susceptible clones. Ostry and McNabb (1983) observed that the rust impact was more severe on poplars in areas planted within the natural range of larch; although PCA plantings are located in the range of larch, no impact was observed in natural stands of poplars.

Leaf Curl Midge

Brief Life History

The adult leaf curl midge is a 3-mm long, fragile, long-legged, gray, mosquito-like insect. From early June to late September, all stages of the insect are present (Morris 1981). Although adult flight habits, mating, egg laying, and feeding have not been observed in the field, Morris (1981) suggests that the adults may congregate in mating swarms at dusk and oviposition may occur in branch tips at night. Eggs are oval, transparent, and about 0.3 x 0.1 m in size. Newly hatched larvae are white, legless, and "maggot-like." In summer, mature larvae drop to the ground and burrow to a depth of about 5 cm and pupate. Overwintering larvae burrow about 15 cm, then in spring they move up nearer the surface, construct pupal cells, and then pupate inside the larval skins (Morris 1981). Morris (1981) reported that as many as five generations of the midge can occur between June and September in southern Ontario.

Damage

Each midge generation can damage or kill one to six leaves during an infestation (Morris and Oliveria 1976). Damage is caused by the tiny maggots which feed in the developing leaves and prevent full expansion of developing leaves. Lightly damaged leaves may develop normally or become dwarfed, crinkled, unrolled and of little use to the tree (Morris and Oliveria 1976). Heavily damaged leaves usually do not unroll, but turn black and drop from the tree. Continuous defoliation of new terminal leaves by the midge results in tip mortality. If tip mortality occurs, lateral branches will compete for terminal dominance, resulting in a forked terminal.

Methods and Materials

During the summer of 1981, two study plots were installed in the nursery to determine the impact of the leaf curl midge. Plot sizes were 30.5 m x 7.3 m. The first plot was six rows wide and contained the following clones: DN-9 - P. x euramericana 'Lons', DN-18 - P. x euramericana 'Tardif de Champagne', DN-22 - P. x euramericana 'I-262', DN-28 - P. x euramericana 'Ostia', DN-30 - P. x euramericana 'Canada Blanc', DN-34 - P. x euramericana 'Eugenei'. Two or three of the dominant whips from each stool were rated according to the number of leaves infested. The following ratings were used: 0 = no damage, 1 = trace, 2 - 4 = light, 5 - 8 = moderate, 9 - 16 = heavy, 16+ = severe.

A second plot was established in the trickle zone at PCA to determine the effects of irrigation on midge population levels. In the trickle zone, only DN-34 and DN-17 (*P. x euramericana* 'Robusta') were included in the study area. Plots were watered once every two days in both study areas.

In 1982, trees within Logan 24 were examined for midge damage. This plantation was established in 1979 with rooted and unrooted mixed planting stock on a 2.4 x 3.0 m spacing. Seventy-five trees in the study area were measured and levels of midge damage were recorded. Damage levels were as follows: 0 = no damage or no fork, L = lightly forked, M = moderately forked, H = heavily forked. A t-test for unequal number of observations was used to analyze data.

Results and Discussion

In the PCA nursery, the average height of infested whips was 0.8 m with a range of 0.7 m to 1.5 m and an average infestation level of 97 percent. The range of infestation was from trace to heavy, with an average rating of heavy. DN-20 was the most severely infested clone in the study. During late August, 1981, this study was terminated due to heavy infestation by the spotted poplar aphid and moderate to heavy infection by melampsora leaf rust.

Study trees within the trickle zone plot showed no signs of midge damage nor were any insects observed feeding during field observations. Therefore, a correlation between the effects of overhead versus trickle irrigation on midge population levels could not be conducted.

Data collected from Logan 24 showed no significant difference at t = 0.1 between height growth in non-forked trees and forked trees although 50 percent of all the trees observed had some degree of fork.

The leaf curl midge could become an important pest in intensive culture management of hybrid poplar if current population levels increase and if interest in hybrid poplars continues. These two factors along with management goals and practices will play an important role in the infestation level of nursery stock and young plantations. Although the study designed to compare the correlation between overhead versus trickle irrigation was abandoned due to lack of midge population in the trickle zone, an observation was made between trees in the "overhead" area. The results showed no correlation between irrigation and decreased infestation. Therefore, I have concluded that overhead irrigation seems to have little effect on midge population.

In the nursery test, the midge also showed clonal preference by attacking the DN clones (*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*) but not NE-19 and NE-20. The two NE clones were growing in the same row as the DN clones and were less than 15 cm from them. In each row when the clone changed from DN to NE the infestation stopped. A similar observation was also noted on Logan 24, where the infested trees were all NE-308 (*P. nigra* var. *charkowiensis* x *P. nigra* 'Incrassata'), although the plantation was established with mixed planting stock. Trees identified as NE-308 were infested throughout the plantation while adjacent trees with different parentage showed no signs of attack. Terminals of heavily infested trees died during late summer 1982; by spring of 1983, the most heavily infested trees were forked. Although no significant height differences were observed between non-forked trees and forked trees, it was highly significant that only NE-308 was infested when compared with the 60 or more clones growing in Logan 24.

Spotted Poplar Aphid

Brief Life History

The spotted poplar aphid is dark blue to black with grayish spots. It is abundant from late July to late September or mid-October and feeds on both aspen and poplar. It appears to have two or more generations per year.

Damage

The aphid feeds on the terminal foliage. Clustering in tightly nested colonies, they often cover the entire growing tip and the first two or three ranks of leaves. Heavily infested leaves curl; some turn black and drop off.

Methods and Materials

In a trial sample in 1979, I examined 11 clones for aphids in a rooting bed in the overhead irrigation area near the center of the nursery where the infestation was heaviest. Colonies were assessed on 35 to 100 whips per clone on August 22. One whip for each cutting was examined and assessed for the presence or absence of aphids, and colonies were ranked by size on a geometric scale as follows:

0 - no aphids;

1 - a few aphids or a small colony on the growing tips on one or two leaves;

2 - a small colony on the growing tip and covering two or more upper unfolding leaves;

4 - a medium colony covering 2 - 3 cm of the growing tip and leaves; a few leaves curled and distorted;

8 - a large colony covering 4 - 5 cm of the growing tip and leaves; some curled or cupped leaves;

16 - a very large colony covering more than 5 cm of the growing tip and leaves; several leaves tightly curled and wrinkled.

Colony size was considered in the analysis because it could be indicative of impact on performance. Sampling was repeated in 1980 on 50 whips of all the clones in the nursery and in both the overhead and trickle irrigation areas. Stools in the overhead zone were 2 years older and had been attacked in previous years.

Growth impact was assessed on a small scale in 1979 on two *P. x jackii* clones (DBJ2-1 and DBJ-2) which were the most heavily atacked clones. The test included 36 whips selected with large aphid colonies and 18 comparable whips without aphids. Half (18) of the aphid-infested whips were sprayed with a conventional dosage of malathion to kill the aphids in order to observe growth recovery of the whips. The whips were measured for height on October 19 after the aphids were gone and the trees had hardened off.

Two insecticidal soaps were tested in 1981 against large aphid colonies on two clones (DN-22, DN-55) at the PCA nursery using recommended full strength (1.0 percent) and half strength (0.5 percent) dosages. The chemicals tested were Safer Insecticidal Soap® concentrate containing 50.5 percent potassium salts of fatty acids and 10 percent

Mono-L-Pesticide IV (MLP-IV) developed in the Department of Biomechanics at Michigan State University. It was also tested at 0.5 and 1.0 percent active ingredients. Colony size was estimated before the test and then sprayed on August 12 between 1:15 and 3:00 p.m. Post-spray counts were made on August 13. Ten whips were used in each data set.

Additional spray tests were made with MLP-IV on clones DN-28 and Raverdeau at the Hramor *Populus* nursery at Manistee, MI. Dosages and number of trees were the same as in the PCA test. Spraying was done on August 14 from 9:00 - 10:00 a.m. and counts taken at 3:00 p.m. the same day.

Results and Discussion

The spotted poplar aphid has been a perennial pest in the PCA nursery in recent years and has shown a wide range of clonal preference (Table 10). Clones of *P.* x *jackii* were the most susceptible to the aphid having the most numerous attacks and largest aphid colonies in the overhead irrigation zone. In this zone, five *P.* x *jackii* clones had an average rating of 6.2 with a range of 0.8 to 10.7. The trickle zone contained only one *P.* x *jackii* clone; it had a rating of 0.4.

When compared, mutual clones growing under both irrigation regimes showed a positive difference between

Table 10. Susceptibility ranking of hybrid *Populus* clones to *Aphis maculatae* under two irrigation regimes at the PCA nursery, 1979-1980

Trickle irrigation		Overhead sprinkler			
Clone	Mean rating[1/]	Clone	Mean rating[1/]	Clone	Mean rating[1/]
DN-18	0.0	D-38	0.0	DN-28	2.0
DN-55	0.0	DN-34	0.0	NE-252	2.1
L-239	0.0	NE-20	0.0 (0.1)	NE-388	2.2
NE-205	0.0	NE-224	0.0	NE-1	2.6
NE-238	0.0	NE-238	0.0	NE-387	2.8
NE-278	0.0	NE-375	0.0	NC-5351	3.0
NE-316	0.0	RAV	0.0	DN-22	3.1
NE-318	0.0	MIL	0.0	NE-225	3.1
NE-366	0.0	I-45/51	0.0	DN-55	3.5
NE-367	0.0	DN-96	0.1	GRJ-6	3.5 (1.9)
RAV	0.0	NE-19	0.1 (0.0)	NE-359	3.9 (1.8)
S-264	0.0	NE-214	0.1	NE-264	4.0
NE-206	0.1	NE-346	0.1	NE-265	4.4
DN-21	0.1	NE-373	0.1	NE-41	4.4
DN-3	0.2	NE-374	0.1	NE-10	4.8
DN-34	0.2	H-96	0.1	NE-386	5.5
L-316	0.2	H-106	0.1	LUJ-7	6.3 (0.8)
I-65A	0.2	NC-5258	0.1	NE-298	6.4
WIS-5	0.2	DN-30	0.2	NE-209	6.5
NE-47	0.2	DN-34	0.2		
NE-252	0.3	NE-308	0.2	NE-360	7.5
DN-28	0.4	NE-206	0.2 (1.8)	DBJ2-1	8.3 (10.7)

Table 10 continued

Trickle irrigation		Overhead sprinkler			
Clone	Mean rating 1/	Clone	Mean rating 1/	Clone	Mean rating 1/
JAC-7	0.4	DN-19	0.3	DBJ2-2	9.1 (8.2)
MIL	0.6	H-48	0.4	LJ-14	9.7 (3.2)
NE-386	0.7	NE-351	0.4		
NE-387	0.7	NE-255	0.5		
DN-17	0.8	NE-318	0.5		
NE-51	0.8	NE-207	0.6		
NE-264	1.3	NE-299	0.6		
DN-5	1.4	DN-18	1.2		
NE-300	1.6	DN-17	1.3		
NE-353	1.7	DN-55	1.7 (1.1)		
L-296	1.7	NE-300	1.9		
NE-225	2.2	NE-252	2.1		

1/ Numbers in parentheses from 1979 data, others from 1980; rating range is 0 to 16 (no aphids to very large colony).

trickle and overhead irrigation; however, the difference was not significant (Table 11). Clones in the trickle zone had a lower rating than the same clones in the overhead zone. The population level difference between clones ranged from 0 difference (RAV and NE-238) to (NE-386).

These results lead one to suggest that nursery stool beds with overhead irrigation are more vulnerable to attack by the spotted poplar aphid than beds with trickle irrigation. However, the aphid population difference between these two irrigation regimes might have been due to the age of the two stool beds. (The stools with overhead irrigation were 2 years older than those with trickle irrigation.) These older stools also produced larger and faster growing sprouts.

The 1979 growth impact study on DBJ-2-1 and DBJ-2-2 showed no difference in height growth between uninfected, infested, and sprayed whips within each clone. Malathion sprayed whips showed no growth response when compared to heavily infected untreated whips, even though malathion killed 95 percent of the aphids. These results suggest that the spotted poplar aphid is not a serious pest of hybrid poplars.

Both soap insecticides and dosages controlled the aphids about equally on three of the four clones--DN-22, DN-28, and

Table 11. Comparison of the susceptibility of 15 hybrid poplar clones to Aphis maculatae grown under both trickle and overhead irrigation in the PCA nursery

Clone	Numerical rating		
	Overhead	Trickle	Difference
MIL	0.0	0.6	-0.6
RAV	0.0	0.0	0.0
NE-238	0.0	0.0	0.0
NE-206	0.3	0.1	0.2
NE-318	0.5	0.0	0.5
DN-17	1.3	0.8	0.5
NE-300	1.9	1.2	0.7
NE-225	3.1	2.2	0.9
DN-18	1.2	0.0	1.2
DN-28	2.0	0.4	1.6
DN-55	1.7	0.0	1.7
NE-252	2.1	0.3	1.8
NE-287	2.8	0.7	2.1
NE-264	4.0	1.3	2.7
NE-386	5.5	0.6	4.9

Raverdeau (Table 12). Control was slightly less effective on aphids feeding on DN-55. In both treated areas (PCA and Hramor nurseries) MLP-IV was 2 to 3 percent more effective for controlling aphid populations than Safer when compared at the two dosage levels. MLP-IV, although effective, caused some burning of foliage at Hramor nursery when applied on sunny days.

Cottonwood Twig Borer

The adult cottonwood twig borer lays eggs on the upper surface of leaves along the midrib or the leaf veins. The larvae eclose in about 5 days and feed on the leaf tissue. After the first molt, they tunnel into new shoots to complete their larval development. They pupate in bark crevices or in sheltered areas on the ground.

This insect attacked sprouts in the clonal nursery and trees in several plantations. Signs of attack were small tubes made of silk and boring frass attached to young shoots. Several whips in the nursery were flagged and observed very closely to see if stem breakage would occur due to tunneling. After about 3 weeks, 50 percent of the flagged shoots were removed and dissected. Shoots dissected showed little damage from tunneling by the twig borer. The other 50 percent of the test shoots were observed throughout the growing season and showed no obvious injury.

Table 12. Insecticidal soap tests for *Aphis maculatae* on hybrid poplar clones at the Packaging Corporation of America nursery and Hramor nursery, 1981

Clone	Insecticide	Percentage dosage	No. aphid colonies treated	Mean infestation level	Percentage aphids controlled
			PCA nursery		
DN-22	Safer	0.5	10	7.2	88
	Safer	1.0	9	5.3	91
	MLP-IV	0.5	10	7.2	90
	MLP-IV	1.0	10	6.0	94
DN-55	Safer	0.5	10	6.0	76
	Safer	1.0	10	6.8	77
	MLP-IV	0.5	10	8.4	86
	MLP-IV	1.0	10	7.2	84
			Hramor nursery		
DN-28	MLP-IV	0.5	10	16.0	96
	MLP-IV	1.0	10	16.0	91
RAV	MLP-IV	0.5	10	16.0	93
	MLP-IV	1.0	10	16.0	88

In the Nine Mile Road clonal mixed plantations, trees 20 to 30 feet tall had several attacks on lateral branches but there was no breakage or reduction in growth. Attacked areas on branches were similar in growth to those on shoots in the nursery. Injured branches showed very little gallery formation. All shoots dissected had a "hard, woody" area at the point of borer entry, indicating that the tree was callousing over the larval entry hole and preventing proper larval development.

Though the cottonwood twig borer was not yet a threat in the nursery nor in the clonal plantations in Michigan, it has, however, been a major pest in cottonwood plantings in the South. Morris *et al*. (1975) reported that this insect has as many as five successive generations per year in Mississippi, and with each generation the populations increase.

Snowy Tree Cricket

The snowy tree cricket lives in the crown of trees usually grown in the open. Eggs are laid singly in a row of punctures in the bark of twigs or small branches where they overwinter. Damaged shoots in the nursery and young plantations often break due to wind or ice damage. Infested trees can become bushy and lose their economic value.

Infestation by the snowy tree cricket at PCA was usually confined to the young terminal or lateral branches. Attacked areas show a small row of punctures up and down the twig. I saw no dead terminals but there was some branch mortality; several branch tips died and some broke over.

Cottonwood Leaf Beetle

The cottonwood leaf beetle is a highly prolific insect--females produce an average of 510 eggs (Burkot and Benjamin 1979). There are four generations between May and September, each generation appearing at about 20-day intervals. The adults overwinter in the leaves and debris beneath the host tree.

Newly hatched larvae feed gregariously and skeletonize the foliage. The older larvae spread out and devour entire leaves. When trees are defoliated, they feed on the young bark of terminal and lateral shoots. The adult beetle also feeds on the foliage. Heavy to severe feeding stunts the trees.

While this insect has not been a pest on PCA lands, Moore and Wilson (1983) reported that this cottonwood beetle has become the number one defoliator in several Wisconsin and Minnesota plantings of hybrid poplars. In these plantings the adult beetle has shown a preference for clones with *Aigeiros* and *Tacamahaca* parentage (Harrell *et al*. 1982).

Mourningcloak Butterfly

The mourningcloak butterfly was observed occasionally in both the nursery and clonal out-plantings. The larvae are gregarious feeders and defoliate one tree before moving to adjacent ones. Defoliation of individual trees by this insect was observed in several plantations at PCA from mid-June to mid-September. Attacked trees were either partially or completely defoliated, but no apparent growth loss was observed. The mourningcloak butterfly was a minor pest in this study.

Viceroy

The viceroy butterfly attacks poplar trees throughout the United States. The caterpillars feed on leaves, tender terminal tissues, and buds. If feeding is confined to the leaves, this insect is of little concern, but feeding on the terminal can kill the terminal. New growth from lateral buds during the next growing season results in a multiple-forked crown. Damaged trees produce less pulpwood.

The viceroy occurred over most of the PCA plantings from 1979 to 1982. The larvae were observed feeding on the leaves, tender terminal tissues, and buds from June to September. In 1980 and 1981, several trees in all locations including the nursery were completely defoliated early in the growing season but refoliated about mid-July.

Although damage by the viceroy was very light on individual trees, this insect could become a serious pest if young trees are defoliated in consecutive years from July to early September (Morris et al. 1975).

Grasshoppers

Grasshoppers can be very destructive to young poplar plantings and nursery stock, especially when their normal food source is scarce. These insects feed on the foliage and young tips of poplar from late May to September. From late summer to early fall, eggs are laid in pods in the soil at depths of 2.5 to 7.6 cm. The newly hatched nymphs feed gregariously on young foliage. These insects can be serious in areas with good weed control or during dry weather when the only food source is young poplar trees. Heavy attacks by large grasshoppers can result in complete defoliation, terminal and branch tip mortality, and tree death.

In 1980, grasshoppers defoliated trees in Benzonia 28, Benzie County, MI. Trees on this site were growing in somewhat excessively drained sandy soil with a heavy weed cover. In late July, paraquat was applied to control weeds, and by early August, 90 percent of the weeds had turned brown leaving only hybrid poplar plantings with green foliage.

The insects began feeding on the trees' foliage in early August and by mid-August many of the trees were completely defoliated. They then fed on the current year's growth, but damage was only minor because the population level collapsed. I am not able to explain this collapse but believe it resulted from the lack of suitable food which caused the insect to migrate. Trees damaged by these grasshoppers recovered during the 1981 growing season.

Leaf Miners and Rollers

Leaf miners (Gracillariidae) were observed feeding on the clones of hybrid poplars throughout PCA lands. The adult female deposits eggs along the midrib or on the underside of the leaf. The newly hatched larvae are small and very flat. They mine within the leaf between the upper and lower leaf surfaces. Mature larvae spin silken cocoons within the feeding mines and pupate. They overwinter as larvae, pupae, or adults, depending on the species.

Leaf rollers (Tortricidae) were observed feeding on the leaves of young poplar plantings on PCA lands. Attacked leaves were either rolled or folded forming enclosures in which leaf rollers could rest and feed. Larvae were usually present from late June to late September. All poplar clones showed signs of attack.

Oystershell Scale

The oystershell scale was observed on the main stem and lateral branches of young poplar trees in the clonal trials. The female scale resembles a miniature oystershell and is chestnut brown or darker. Eggs overwinter under the females' scales. Nymphs hatch in June and crawl for a short time, then settle down to feed. Nymphs feed primarily on the twigs, branches, and thin-barked stems and prefer shady conditions. Attacks on some trees were heavy enough to form a small crust on several branches.

Cottony Maple Scale

The cottony maple scale adults were observed on the main stem and lateral branches of young poplar trees at PCA. The adult female is maroon with a mid-dorsal keel that is yellow-brown. Eggs are laid on newly developed leaves in spring. After hatching, the nymphs scatter over several leaves and settle along the leaves' midribs and large veins. In summer, large, white, cottony egg sacs extend from the rear of the female. Heavy infestion by the scale can result in yellowing foliage, branch mortality, and reduced tree vigor and growth, but no damage was observed on poplar trees at PCA.

Leaf Spots

Septotinia podophyllina attacks young developing leaves in early spring. The fungus first appears as small brown spots that increase rapidly in size becoming gray in the center with an irregular margin. Several spots contain white spore-producing structures and masses of conidiaspores in concentric circles. These spots are characterized by mycelia and sporodochia just below the upper leaf surface.

The fungus overwinter in fallen infected leaves as scelerotia. In spring, ascospores are forcibly discharged into the air during wet weather. Spores are carried by wind and rainsplash to developing leaves where infection occurs. In summer, secondary infections occur from conidia in leaf spots that are rainsplashed to adjacent leaves.

Venturia spp. are leaf and shoot blights that infect only the current year's leaves and shoots. Symptoms first appear in May on leaves as small angular black spots, which later cause the leaf to become curled and distorted. Infected shoots turn black and curl to resemble a "shepherd's crook." These infections are caused by conidia produced from mycelia in shoots killed the previous season, or by ascospores which develop in fallen infected leaves. The condia appears as an olive-green layer on nearby infected tissues, which are carried by rainsplash to new growth causing secondary infections that can multiply rapidly.

The disease can cause terminal and shoot mortality and distorted shrubby growth. In young plantations and clonal nurseries, growth losses and tree mortality can be serious, due to repeated attacks.

Phyllosticta spp. produce small brown spots on the upper surface of leaves in the spring. Leaf spots contain pycnidia which produce pycnidiospores. Infections on tolerant trees are usually associated with insect wounds; although, on highly susceptible trees, no wounds are necessary for infection to occur. The fungus overwinter on fallen infected leaves. In spring pycnidiospores from overwintered leaves spread to developing leaves by wind and rainsplash. Summer infections are produced by pycnidiospores produced within the initial infection.

DISCUSSION

From 1978 to 1983 intensive culture hybrid poplar research and management in Michigan has focused mainly on land managed by PCA, but may be applicable to other areas in the North Central States. At PCA I found 19 insects and 10 diseases attacking the Populus nursery and outplantings; of these pests I found six insects and three diseases to be currently important. Wilson (1976) reported that about 150 species of insects and 50 different diseases attack natural growing Populus. He also reported that 15 insects and 5 diseases were important pests in Populus nurseries and clonal outplantings. In this study, septoria gave the greatest disease impact while the poplar-and-willow borer gave the greatest insect impact. Both are stem problems.

Septoria cankers and leaf spots caused the most impact on clones at PCA with *P. maximowiczii*, *P. laurifolia*, and *P. trichocarpa* parentage. Waterman (1954) concluded that *P. maximowiczii* crosses were susceptible to infection by septoria but that these clones were rarely injured. She also suggested that because these trees maintained good growth and vigor they could ward off the disease. In my study, however, these trees did not maintain good growth and vigor; in areas of heavy infection tree tops and total tree mortality resulted. This difference in tree performance might have been due to local weather, soil conditions, and location. McNabb *et al*. (1982) also reported clones with these parentages were highly susceptible to septoria infection throughout the North Central Region. At PCA, the most tolerant clones to septoria were NE-19, NE-20, NE-308, NE-353, RAV, and DN-34. However, McNabb (1982) reported that NE-19, NE-308, NE-353, and NE-20 were beginning to lose their tolerance to septoria in outplantings in Iowa, Wisconsin, and Minnesota. In the southern United States, Morris *et al*. (1975) observed septoria to be a pioneer disease canker organism which allowed *Fusarium solani* (Mart) Snyder and Hans., *Cytospora chrysosperma* Fr., *Phomopsis macrospora* Kobayshi and Chiba, and *Botryodiplodia theobromae* Pat. to invade the tree through its cankers.

The poplar-gall saperda, while abundant in only one stand at PCA, caused relatively little impact on intensively cultured hybrid poplar. Nord (1968), Grimble (1969), and Hussain (1972) observed tree mortality in native *Populus* stands as a result of borer activity. They also reported that the greatest impact was on trees located in isolated stands or in old fields. In my study, the heaviest attacks were in an isolated plantation bordered by mature native *Populus*. Trees attacked by this insect are seldom killed; however, top-kill did occur to several trees. This insect does have the potential to cause wide-spread tree mortality as more and more hybrid poplar plantations are planted. Large whips as planted at PCA offer suitable habitats for brood development during their first year of growth.

The poplar-and-willow borer attacks at PCA were limited to isolated trees in several plantations except in one stand where clones of Raverdeau and NE-353 were attacked. Attacked trees were seldom killed, but several trees suffered top kill and reduction in growth. This insect does not occur south of 70° north latitude. Vallee (1979) reported that the poplar-and-willow borer was the most serious insect attacking poplars in Quebec. This borer is also a serious pest in Europe on poplars and willows (Baker 1972). Morris (1981) found that in Canada the borer-infested trees were usually 3 years old or older with a and basal diameter over 4 cm. He also observed that DN-1, DN-3, DN-25, and DN-70 were the most resistant (no infestation) while DN-26 and DJAC-4 were the most heavily infested (67 percent and 80 percent, respectively). In this study Raverdeau was the most susceptible.

The willow shoot sawfly was observed attacking young shoots in the PCA nursery. This insect showed little clonal preference and attacked the tips of shoots at random. I found that the most tolerant clones were DN-17, DN-18, and DN-19, while DN-34, WIS-5, DN-9, 5258, and DN-55 were the most susceptible. Infested tips were girdled by the female during oviposition. Girdled tips at PCA wilted within hours after attack and after several weeks turned black and broke off at the point of injury. Although not a serious pest at PCA, the willow shoot sawfly has the potential of becoming an important pest of intensively cultured hybrid poplars if increases in population size occur and if the number of ha planted to hybrid poplar continues to increase. In Mississippi, Solomon and Randall (1978) found that this insect was a serious pest of nursery-grown willow; highly susceptible rootstock shoots were 100 percent infested. They also observed that damaged shoots wilted during the first hour after attack.

The tarnished plant bug was the most damaging insect in the nursery. It infested shoots of all sizes and most of the clones in the nursery. The degree of damage to clones ranged from light to heavy indicating a wide range of tolerance between clones. Lesioned stems reduced the quantity and quality of planting material. WIS-5 was the most damaged clone while NE-359 was the most resistant;

DN-34 planting stock from a nursery and a windbreak had both light and moderate injury. Sapio et al. (1982) found that planting white clover would reduce the impact of TPB on young shoots. However, if clover is planted between the rows and overhead irrigation is used in the planting area, the increased moisture level would favor the build-up of septoria. Another approach would be to rogue WIS-5 and DN-34 from the nursery and avoid future field planting of these clones, even though they perform better than NE-359 on a wide range of soils. WIS-5 and DN-34 are among the best clones at PCA because of their ability to grow well in a range of different soil types and environmental conditions, and because of their high level of tolerance to pests.

The cottonwood leaf beetle, although observed at PCA, has not been a problem in Michigan, although Harrell et al. (1982) reported that this pest is one of the most serious defoliators of hybrid poplars in the North Central States. Their observations were similar to Morris et al. (1975), who reported that the CLB caused serious damage to young cottonwood trees in nurseries and plantations. Harrell et al. (1982) observed an adult feeding preference for the foliage from the Tacamahaca clones when compared to the Aigeiros clones in Wisconsin. Caldbeck et al. (1978) evaluated hybrid poplar clones in Rosemount, MN, and Ames, IA, and observed that the CLB had six generations/year in Ames and three generations/year in Rosemont. They also reported that clones either poorly or heavily attacked at one location were similarly attacked at the other location. The most resistant hybrid poplar clones to the CLB in the North Central Region are 5339, NE-1, NE-19, 4877, and 5261. However, clone NE-1 is very susceptible to septoria. The most susceptible clones are NE-375, NE-386, NE-252, WIS-5, NE-387, and NE-372. Clones NE-386, NE-252, and NE-387 are also highly susceptible to septoria.

The spotted poplar aphid showed a wide range of host preference in the PCA nursery. The insect was observed feeding on the current year's shoots; however, heavy feeding was limited to *P. x jackii* and NE-360, the most susceptible clones. *P. x jackii* is also very susceptible to melampsora leaf rust. Though the impact of the spotted aphid is not serious on *P. x jackii*, this clone acts as a reservoir and probably should not be planted because of its susceptibility to melampsora infection. In such cases, NE-19 might be planted in its place in areas where the pests are abundant because of its high level of tolerance to both pests.

The leaf curl midge was observed feeding in the clonal nursery and in several plantations. In the nursery the insect attacked shoots less than 1.5 m while in plantations it attacked trees as tall as 7 m. The impact in the nursery was light while in the heaviest infested plantation (Logan 24) the impact was medium. This insect was reported by Morris (1981) to be a major pest in nurseries on young shoots; he also reported that as many as five generations/year exist in southern Ontario. Morris and Oliveria (1976) reported that the impact caused by this midge could be reduced by heavy rainfall. In my study that used overhead irrigation, no reduction in midge impact or population was observed. In the nursery, the midge preferred the DN clones as compared to NE-19. However, in one planting it preferred NE-308. The clones hardest hit by the midge are among the best performing clones at PCA, for example, NE-308 and DN-34. Because the midge killed the terminals of trees up to 7 m tall, it could very well become one of the more important pests of pole-size hybrid poplars in the North Central Region.

Marssonina leaf spot occurred on all poplar clones examined at PCA, although no impact from this disease was observed. However, Jokela _et_ _al_. (1976) found that in Illinois and Iowa, marssonina is a threat to intensively managed cottonwood. During their study they also observed a number of resistant clones; however, in our study no clones were resistant, although NE-19, NE-20, and NE-308 showed high levels of tolerance.

Melampsora leaf rust attacks the leaves of poplars and causes premature defoliation. The impact of this disease is reduced because infection occurs late during the growing season. *P.* x *jackii*, the most susceptible clone, was completely defoliated from late August to mid-September but had no measurable growth loss.

At this writing, the following eight clones are the best for outplanting on PCA lands: NE-308, NE-238, NE-19, NE-20, RAV, WIS-5, DN-55, and DN-34. These clones have a high level of tolerance to pests and have grown well in different soil types on PCA lands. Clones that should not be planted at PCA: NE-41, NE-235, NE-388, NE-47, NE-1, and *P.* x *jackii* because the NE clones are highly susceptible to septoria canker and *P.* x *jackii* is highly susceptible to melampsora.

Future plans include research on the effect of the poplar-gall saperda, poplar-and-willow-borer, and septoria canker on wood degradation, and on the impact of the willow-shoot sawfly, tarnished plant bug, spotted poplar aphid, melampsora, and marssonina. Plans provide for monitoring PCA plantations and their clonal nursery for new pests and changes in pest populations currently under study. One goal is to have available for growers a hybrid poplar pest management manual that would include most of the pests observed in Michigan, various control strategies for each pest, and recommendations for clone planting on the best sites.

PEST MANAGEMENT PLAN FOR HYBRID POPLARS

Many growers see intensively cultured hybrid poplar management as the answer to our wood shortage because they believe these trees will grow under all types of weather conditions and on any site. Several producers are also guilty of this claim; they advertise that poplars will grow in a range of soils from dry rocky outcrops to exessively wet swamp sites. This is partly true--trees within the genus _Populus_ will grow in a wide range of conditions, but their performance might be poor.

Planting stock should be obtained from a reputable nursery. The nursery is the most important input in the total system for growing intensively cultured hybrid poplars because management of poplars in the nursery is reflected in tree performance in the field.

The nursery should be established on a well-drained, sandy loam soil to allow for good root penetration during establishment. The site should be free of all native and hybrid _Populus_, including windbreaks with _Populus_ adjacent to the site. Before planting, the area should be subsoiled to a depth of 0.5 to 0.8 m to destroy the hardpan layer, therefore increasing root aeration and water movement. After subsoiling, one should use a bottom plow to turn under any remaining vegetation, followed by a disk and section harrow to put the final touches on soil preparation. With soil prepared, soil sample cores should be taken and analyzed to determine soil fertility and nematode population. Prior to planting, the area should be fumigated to destroy soil inhabiting micro-organisms.

The nursery should have an irrigation system that can be employed during dry weather to avoid moisture stress. This irrigation system can be overhead, trickle, or both and can be permanently installed or portable.

Planting beds should be prepared using a tractor-powered rototiller to ensure good root penetration. Beds should be spaced about 0.9 m apart to allow for cultivation with a rototiller or tractor to reduce weed competition and increase aeration. Weeds not controlled by cultivation should be treated with a registered herbicide. Herbicides should be applied with care to avoid contact with poplar shoots because most weed herbicides will also kill poplars.

Insects and diseases are a major problem in the nursery. These pests should be controlled through the use of mechanical and chemical means. In areas with overhead irrigation, trees should be watered in the morning to allow the foliage to dry during the day, thereby reducing the impact of septoria leaf spot and canker infection. Removal of leaves and twigs during the growing season and after harvest will also reduce the septoria innoculum level. As far as PCA is concerned, clones with P. maximowiczii, P. laurifolia, and P. trichocarpa parentage should not be planted in the nursery because of their high susceptibility to septoria infection.

Melampsora leaf rust is the second most important disease organism affecting nursery stock, and this disease is most damaging to P. x jackii late in the growing season. Because jackii clones are also very susceptible to aphids, jackii clones should be avoided.

The tarnished plant bug, the most damaging insect in the nursery, infests shoots of all sizes and from most of the clones. Using shorter planting stock with highly susceptible clones such as WIS-5 alleviates part of the problem. Because this insect has a wide range of hosts, one method of control could include the planting of "trap crops," which could be planted in strips between clones or rows. In addition, weed control could be very intense during plantation establishment but reduced later in the growing season as the plantings become more established because TPB feeding damage occurs late in the growing season.

The impact of the TPB, septoria, melampsora, spotted poplar aphid, willow shoot sawfly, and marssonina on clones growing in the PCA hybrid poplar clonal nursery has been low. However, the potential exists for an individual pest or combination of these pests to become a serious problem. Because nursery managers are interested in growing enough planting material to meet the expected demand for poplar, many stress the use of pesticides, for they think pesticides are inexpensive, effective, and easy to apply with little manpower.

Once shoots are ready for harvest, the nursery manager has the responsibility of ensuring that shoots are graded and properly stored for planting. Shoots harvested before dormancy do not grow very well because their food reserve is low; in many cases this reserve is too low to support bud burst and new growth, resulting in tree mortality. These food reserves also assist the trees in their defense against insects and diseases.

During the grading process, trees should be inspected not only for growth deformities but also for the incidence of insects and diseases. Shoots containing insects and diseases should be piled and burned to destroy these pests. It is important that pest shoots not be processed for planting because they can serve as epicenters in newly established plantations.

Proper storage of whips and cuttings is very important for the nursery manager because improper storage of planting material could also result in plantation failures. Planting material stored during the winter at temperatures greater than 3°C usually start bud burst before spring planting. Premature bud burst makes the material useless as planting stock. If the temperature is allowed to fluctuate during storage, moisture will develop in the plastic bags resulting in mold formation. Repeated temperature fluctuations on planting stock during storage results in black stem infections in the first growing season. Black stem infection will usually kill both terminal and lateral buds/shoots.

Hybrid poplar plantations have many of the same pest problems as the clonal nursery, however, pest impact is usually not as heavy. In plantations, factors like site selection, site preparation, moisture stress, weed competition, etc., play a major role in the overall vigor of the tree, which is directly related to the level of pest incidence.

Site selection is next in priority. Areas selected for planting should be evaluated for soil type, depth, moisture, aeration, fertility, pH, and drainage. Hybrid poplars grow best on sites containing deep, medium-textured soils, which allow for root penetration to at least 1 m before being interrupted by hardpans, high water tables, gravel layers, bedrock, etc. Soil drainage affects both soil moisture and aeration, thereby determing water-holding capacity and root penetration. If drainage is poor, soil moisture and water-holding capacity are high, reducing soil aeration and root penetration. Planting on these sites would limit tree survival and production.

Soil fertility and pH are also very important in site selection. Because poplars extract more nutrients from the soil than most trees, the site selected must be high in natural fertility. Increased fertility can be accomplished by applying chemical fertilizers or municipal sludge or by establishing a cover crop before planting or a nurse crop like soybeans at the time of planting. Optimum soil pH is in the range of 5.5 - 7.5. On acid soils with pH below 5.5, lime should be added to increase soil pH within the optimum range.

Sites planted with corn in the previous year should not be planted with poplar for 2 or 3 years due to the build-up of herbicide residues in the soil. Residues can severely limit plantation establishment and survival, and poor performance will attract insects and diseases.

Dickmann and Stuart (1983) assessed the various soil factors that affect poplar growth on a given site in Michigan. To accomplish this, they adapted the work of Baker and Broadfoot (1976, 1979), that determine site-quality ratings for cottonwood growth on Mississippi Delta sites. Table 13 taken from Dickmann and Stuart (1983) can be used as a guide to select poplar planting sites.

Site Preparation

Once the planting site is selected, site preparation is the next step. The degree of site preparation will depend on prior land use, current vegetation, and site condition. The methods used for site preparation involve tillage, no-till, or a combination approach of tillage and no-till. If tillage is used and if the site is an old field, the land should be prepared with a chisel plow or subsoiler to break up any hard pans. Next use a bottom plow to turn under existing vegetation, followed by disking. Bottom plowing and disking not only destroy vegetation but also create a good planting bed. Areas with heavy sod or perennial vegetation should be disked several times during the summer

Table 13. Some factors that affect the productivity of soils for hybrid poplars[1]

Soil Property	Best conditions	Worst conditions
Physical	Deep (>1 m) soils without pans Loose, porous, friable soils (bulk density <1.4 g/cc) Undisturbed site with no recent cultivation or pasturing	Shallow (<0.5 m) soils or soils with plowpans or natural cemented pans Strongly compacted, tight soils (bulk density (>1.7 g/cc) Recent intensive cultivation or pasturing for >20 years
Moisture availability during growing season	Water table 1 - 2 m Level ground or lower slopes No flooding or only early spring	Water table <0.3 m or >3 m Ridgetops, mounds, dunes Prone to flooding any time

Table 13 continued

Soil Property	Best conditions	Worst conditions
Nutrient availability	Undisturbed site or cultivated <5 years Organic matter (A-horizon) >3%; especially in sandy soils A-horizon (topsoil) >15 cm Young, well-developed profile Source of basic (calcareous) parent material in rooting zone pH in rooting zone 5.5 - 7.5	Recent intensive cultivation for >20 years Organic matter (A-horizon) >1%) A-horizon (topsoil) absent or <8 cm Old, highly leached profile No basic (calcareous) parent material in rooting zone pH in rooting zone <4.5 or >8.5
Aeration	Wet by running water only in early spring No mottling to 0.6 m Soil color black, brown, or red	Swampy, stagnant, or waterlogged condition much of the year Mottled to surface Soil color gray

[1]From Dickmann and Stuart (1983).

prior to planting to expose weed roots and rhizomes to the heat and drying of the sun (Dickmann and Stuart, 1983). Disking will also destroy insects like cutworms and white grubs.

Some forest managers planting old fields to hybrid poplars have elected to use no-till as a means of site preparation. No-till involves the application of herbicides like glyphosate or amitrol-T applied in bands or broadcast on mowed or unmowed vegetation in late summer or early fall before planting. In spring, planting material is planted in the brown spray strips. Managers like no-till because it usually involves only one pass over the land, reduces the potential for erosion, and conserves soil moisture. However, this method is not effective in areas with numerous aggressive weeds with rhizomes under the ground. Pest organisms can find protection in untreated areas and attack planting material after planting. No-till offers a poor planting bed and does nothing to break up existing hard pan.

The best approach to site preparation of old fields is a combination of tillage and no-till, which can involve chisel plowing, bottom plowing, disking, and herbicides. For example, a treatment could involve the use of herbicides followed by tillage. If herbicides are applied as a broadcast spray in early spring, treated areas should be disked and fallowed. In late summer or early fall, fallowed areas should be tilled. Another approach would be to use tillage in spring or early summer and no-till in late summer or fall before planting.

If old timber stands are cut and converted to a poplar site, preparation is more intensive. First, all timber and residue must be removed from the site. Residue removal may be mechanical, chemical, or a combination of both. On old forested sites, existing vegetation and logging debris must be removed from the site by cutting, raking, windrowing, and burning. Vegetation too small for these operations or on soil textures that will not permit heavy machinery should be chemically treated.

Planting

The proper planting of hybrid poplars is just as important as site selection and preparation. Planting material can be unrooted hardwood cuttings, rooted cuttings, rooted and unrooted whips, and containerized stock. Unrooted hardwood cuttings and whips should be at least 0.9 cm in diameter. Planting stock should be soaked in water at 4° to 16°C for 7 to 10 days or until small swellings or bumps appear on the bark (Hansen et al. 1983). When soaking, leave cuttings or whips in bundles with buds pointing upward. Immerse to about 3/4 of their length. If soaked material cannot be planted in 2 or 3 days after soaking, it should be placed in cold storage (0°C) and the bundle packed in crushed ice to prevent root and shoot development (Hansen *et al*. 1983).

Rooted stock can be harvested while dormant in late fall and outplanted, or they can be stored in cold storage for spring planting. If stored, stock should be treated similarly to unrooted stock before planting.

Containerized stock increases the survival of small diameter planting stock, extends the planting season, and increases survival on marginal sites. This stock should be treated similarly to the unrooted stock before planting.

The planting of rooted stock, whether containerized or not, offers managers the best survival on all sites and under different weather conditions. Although rooted stock is the best planting material, many landowners cannot afford the difference in cost between the unrooted stock and rooted stock. Hansen *et al*. (1983) state that the cost of planting rooted stock is more than twice that of unrooted stock. However, if managers are trying to produce intensively cultured short rotation hybrid poplar for maximum biomass production, the rooted stock should be used on all sites where vegetation is a problem or site quality is low because rooted stock has a root system that will support new shoot growth. On the other hand, unrooted stock must develop a root system while supporting new growth and competing with unwanted vegetation.

Planting material should be planted with one or two buds above the ground level. Material can be planted with a hand dibble or by machine. When using a hand dibble, make a hole large enough to place the planting stock base at the bottom of the hole. Then pack the soil around the planted stock to eliminate air pockets.

Planting machines can range from modified farm planters to fruit tree planters depending on the size of the planting stock. The modified farm planters can be used to plant cuttings. These machines open a narrow trench in which the unrooted whips or cuttings are placed and packed into the soil with heavy packing wheels. When machine planting rooted stock, heavy-duty planters like the fruit tree planter must be used to open a wide, deep slit, thereby allowing room for stock to be placed in the slit and packed with packing wheels.

Clones selected for planting on PCA lands should omit *P. jackii*, *P. maximowiczii*, *P. trichocarpa*, and *P. laurifolia* as parentage because *jackii* is susceptible to melampsora leaf rust and the other clones are highly susceptible to septoria infection. *P. tristis* grows poorly and bud set is too early in Michigan. Lombardy poplar, although a good grower in the first 2 or 3 years after establishment, begins to die back from the fifth growing season until tree mortality at about age 10 to 15. Seldom do any of these trees reach merchantable size. Clones with *P. deltoides* and *P. euramericana* parentage currently appear to be the best performers on all sites and under adverse weather conditions. Therefore, NE-308, NE-353, DN-34, and RAV clones should be planted.

After selection of planting material and method of planting, the manager's next decision regards spacing. Spacing distance between planting stock and between rows depends on the length of rotation. If closed space (1 x 1 m or less), rotation is 8 years or less; wider spacing (greater than 1 x 1 m) increases rotation from 8 years to 15 years or more depending on site, planting stock quality, and pest incidence levels. The cost of planting material is exponentially related to tree spacing--close spacing can cost nine times as much as wide spacing (Hansen *et al.* 1983). Although planting cost is high in dense plantations, the need for weed control after the first year is usually not required as compared to several years of weed control if wide spacing is used. Therefore some of the differences in planting cost between the two methods can be recovered.

Schipper (1976) reported that stand density can influence the severity of disease in plantations. Dense stands make a more favorable environment for disease development and movement because of reduced air movement through the plantations which increases the duration of leaf and stem wetness resulting from rain, dew, or irrigation (McNabb et al. 1982). Duration of leaf and stem wetness is directly related to infection rates of septoria leaf spot and stem canker (McNabb et al. 1982).

Plantation Maintenance

Weed control is essential for successful establishment of intensively cultured hybrid poplar plantations (Hansen et al. 1983, Schreiner 1945). Control can be accomplished by mechanical or chemical means or by using cover crops. These controls can be used singly or in various combinations. Mechanical control involves disking and/or cultivation. If disking is used, the space between rows and between trees should be the same to allow for good coverage with the same disk. Cultivation can be accomplished using a rolling cultivator, a rotary hoe, or plowing cultivator. The rolling cultivator provides good weed control between rows but not much control between trees because of its inability to throw soil into the spaces between trees. The rotary hoe will control weeds both between and within rows but can only be used when the trees are less than 0.5 m tall. A plowing cultivator will control weeds both between and within rows. This cultivator can be set to carry enough soil to cover young weeds within the row. If planting stock is small, metal fenders mounted on the cultivator and raised about 5 cm above the ground level will protect planting material from being covered. Cultivating must start early in the growing season and continue throughout the season, and can only be used on trees less than 1-m tall.

Deep cultivation can depress growth or distort root distribution and lead to blowdown problems as the tree matures. Therefore cultivation depth should be shallow (5 to 7 cm). Cultivation should begin soon after plantation establishment and continue until the weeds are no longer a threat to plantation survival. Although cultivation is a good method for controlling weeds, it is expensive and dependent on dry weather.

Herbicide control of weeds is believed by many managers to be the most effective and least expensive means of controlling weeds because herbicides can control weeds for an entire growing season with a single application, can be used on till or no-till sites, or can be applied to areas where the ground is too wet to be cultivated. No-till or herbicide-treated sites should be observed very closely during the growing season because these sites offer suitable shelter, reproduction, and infestation/infection sites to pest organisms. This type of management favors the build-up of such pests as leaf spots, septoria, poplar-and-willow borer, cottonwood twig borer, cottonwood leaf beetle, etc. Areas where weed control is good favor the build-up of the tarnished plant bug. However, the impact of the tarnished plant bug can be controlled by planting a cover crop like white dutch clover (Sapio et al. 1982). Clones most susceptible to attack by the plant bug are NE-298, NE-386, NE-387, WIS-5, and NC-9921 (Sapio et al. 1982).

Caution must be taken when using herbicides to avoid drifting and overspray because poplars are very sensitive to herbicides. Herbicides currently in use are glyphosate, simazine, and paraquat.

Cover crops can successfully prevent weed growth prior to planting and some, like clover and soybean, can increase the nitrogen level in the soil. Cover crops, like weeds, will compete with the trees for available moisture and nutrients; therefore, cover crops perform best in irrigated and fertilized areas.

The best management plan for weed control is a combination of mechanical, chemical, and cover crop. For example, areas planted with hybrid poplars should be cultivated and chemically treated during the first 2 years. Herbicides would be applied during cultivation with a shielded sprayer. During the third year, herbicides should be applied early during the growing season when new weed growth appears. On areas with good soil moisture or irrigation, herbicide treatments should be followed with a cover crop.

Pest Management Guide

The following is a management guide for four major pests of hybrid poplars in Michigan: poplar-and-willow borer, poplar-gall saperda, tarnished plant bug, and septoria leaf spot and canker. This guide discusses the host species, the importance of the pest, what to look for to determine pest levels, the biology of each pest, how to monitor pest activity, and how to control each pest.

Poplar-and-willow borer

Hosts: Poplars and willows in Europe, the northern half of the United States, and southern Canada are hosts of the poplar-and-willow borer.

Importance: This insect is a pest of young poplar plantations, especially those that are planted adjacent to infested willow, alder, or poplar trees. Young trees and whips are damaged by larval boring in the main stem. Heavy girdling by the larvae can cause stem breakage and tree mortality.

Look for:

- Coarse boring material and frass around the base of young trees.
- Boring frass protruding from small circular holes in the tree bark.
- Sucker or scarred areas around the bases of young trees.
- Dead trees.
- White grub-like larvae and pupae about 1-cm long in the wood of the stem.
- Black and white weevils, 1-cm long.

Biology: The female weevils mate 2 to 10 days or more after emergence. Ovipositioning for overwintering adults occurs during March and April, and for newly emerged adults from July through September. Eggs are deposited by the female in slits chewed in the bark lenticels and wounds of the main stem. The young larvae tunnel in the cambium layer around the circumference of the stem. Late instar larvae tunnel toward the center of the tree, and after enlarging the tunnel, they pupate and either overwinter or emerge as adults depending on local weather conditions.

Monitoring: Examine young shoots and trees with basal diameters between 1.8 and 7.4 cm from early May to October for the presence of adult weevils. In late spring and early summer, examine the main stem for fine, black boring frass. In late summer, examine sprouts and trees for slightly small or indented areas around the bases of trees 1- to 3-years old. In older trees look higher on the main stem for these signs. If more than 10 percent of the trees are killed, chemically treat the entire plantation.

Control:

- Plant resistant clones.
- Don't plant stock adjacent to infested willow, alder, or poplar trees.
- After harvesting, remove all infested material before replanting or stump coppice to reduce population levels and attacks on new sprouts.
- In heavily infested areas, apply an insecticide that is registered for use against wood boring insects to the main stem of trees in late March or early April--just prior to adult emergence--then again in July.

Poplar-gall Saperda

Hosts: All poplar species, both natural and hybrids, from northern Minnesota, southeastern Ontario, and southern Quebec to southern Illinois and east to Pennsylvania host the saperda. In the west it occurs from northern Manitoba and Saskatchewan to southern Colorado.

Importance: This insect is a pest of young plantations and nursery stools. Young trees and whips are damaged by larval boring in the main stem or branches. Heavy girdling can cause stem and branch breakage and tree mortality.

Look for:

- Dead branches.
- Dead tops of trees <0.3 m tall.
- Dead trees.
- Horseshoe-shaped scars (egg-niches) on the stems or branches which were cut by the adult beetle.
- Galls (swollen areas) on the stems or branches.
- White larvae or pupae, 1-cm long, within the central pith of the gall.
- Gray long-horn beetle, 0.5- to 1-cm long. Adults are on the foliage or stem during May and June.

Biology: The female beetle lays eggs in the bottom of horseshoe-shaped egg niches cut into the main stem and branches. The larvae feed on the woody tissue, boring irregular tunnels under the bark. A globose swelling or gall forms around the infested area as a result of larval tunneling. In late summer the larvae bore toward the center of the gall and after enlarging the tunnel, they pupate and overwinter.

Monitoring: Examine sprouts and young trees with a basal diameter greater than 1 cm from early May to late June or early July, for horseshoe-shaped egg niches. In late summer examine sprouts and trees for galls. If more than 10 percent of the trees are killed, treat the entire plantation.

Control:

- In heavily infested areas, apply an insecticide that is registered for use against wood-boring insects to live trees between mid-May and late June, when the adults are most active.
- Do not plant stock in isolated plantations or along right-of-ways.
- After harvesting, remove all infested material before replanting or stump coppice to reduce population level and attacks on new sprouts.
- Don't plant offsite.

Tarnished Plant Bug

Hosts: The tarnished plant bug feeds on agronomic crops and weeds, flowers, and vegetables throughout most of North America.

Importance: This insect is a pest of young nursery shoots towards the end of the first growing season. Feeding by numphs and adults can cause stem and branch breakage.

Look for:
- Dead tops of trees <2 m tall.
- Small bumps on the current year's growth.
- Split-stem lesions.

Biology: The tarnished plant bug nymphs and adults feed on the sap of young poplars throughout the growing season. The eggs are deposited in leaf petioles, in buds, and in the bark of young shoots. The nymphs hatch in about 10 days and immediately begin feeding on the sap. The newly hatched nymphs feed by inter- and intra-cellular stylet penetration, and secrete saliva that causes the stem to develop a split-stem lesion at the point of attack.

Monitoring: Examine sprouts and young trees from early spring to late summer for presence of lesions on the stem or branches. If the number of attacks in the nursery increases in late summer and if 95 percent of the whips in any one clone have lesions in the upper one-third of the tree, managers should consider culling only the damaged portion.

Control:
- Plant resistant clones.
- Do not plant trees adjacent to corn, soybeans, cotton, and vegetable truck farms.
- In the nursery, plant a trap crop like alfalfa and keep it mowed to allow for new growth.
- In young plantations no control is recommended.

Septoria Leaf Spot and Canker

Hosts: All poplar species, both natural and hybrid, from the old world to the new world host the septoria leaf spot and canker.

Importance: This disease is a major pest of young plantations and nursery stools. Young trees and whips are damaged by leaf infestation or cankers. Heavy cankering can cause stem and branch breakage or kill trees.

Look for:

- Dead branches.
- Dead trees.
- Leaf spots on the upper side of the leaf.
- Cankers on both the stem and branches.
- Depressed areas on the stem and branches.
- Multiple-forked trees.

Biology: Septoria produces both leaf spots and cankers on trees of various ages and sizes. The pathogen overwinters on fallen infected leaves and in branch and stem cankers. Spores are carried by rain splash and/or wind to leaves, stems, and branches throughout the growing season. New infections can increase rapidly under moist conditions. Infections are most severe in nursery stools where moisture is high due to close spacing and irrigation.

Monitoring: Examine shoots in the nursery and plantation from early May to September for the incidence of leaf spots and cankers. Examine the stem and branches for the presence of cankers throughout the growing season. If more than 10 percent of the trees are cankered within the nursery or plantation, use direct control.

Control: Nursery

- Plant resistant clones.
- Apply a registered fungicide to the infested trees.
- Rogue infected clones from the nursery.
- If overhead irrigation is used, apply in the morning to allow excess moisture to evaporate.
- Establish nursery stool beds at 1 m or wider.
- Plant stools 0.4 m apart or more.
- After harvest, remove infected material.

Plantations

- Plant resistant clones.
- Apply a registered fungicide to infected trees.
- If the plantation is established in blocks, remove only the blocks of clones infected

with septoria.

- Remove all infected material after each harvest before replanting or stump coppice to reduce infection levels.
- Plant trees in good sandy loam soil to maintain vigor.

APPENDICES

LIST OF REFERENCES

Appendix I. Hybrid poplar clones planted in the PCA nursery

Clone	Parentage
NE-1	*P. nigra* x *P. laurifolia* 'Stratglass'
NE-9	*P. nigra* x *P. trichocarpa*
NE-10	*P. nigra* x *P. trichocarpa*
NE-11	*P. nigra* x *P. trichocarpa* 'Roxbury'
NE-12	*P. nigra* var. *betulifolia* x *P. trichocarpa* 'Andover'
NE-16	*P. nigra* var. *charkowiensis* x *P. deltoides*
NE-17	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*
NE-19	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*
NE-20	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*
NE-32	*P. deltoides* var. *angulata* x (*P.* x *berolinensis*)
NE-41	*P. maximowiczii* x *P. trichocarpa* 'Androscoggin'
NE-47	*P. maximowiczii* x (*P.* x *berolinensis*) 'Oxford'
NE-48	*P. maximowiczii* x *P. berolinensis*
NE-50	*P. maximowiczii* x *P. berolinensis*
NE-55	*P. balsamifera* var. *subcordata* x (*P.* x *berolinensis*) 'Maine'
NE-58	*P.* x *rasumowskyana* x *P. nigra*
NE-98	*P. nigra* x *P. laurifolia*
NE-205	*P. nigra* x *P. laurifolia*
NE-206	*P. deltoides* x *P. trichocarpa*
NE-207	*P. deltoides* x *P. trichocarpa*
NE-209	*P. deltoides* x *P. trichocarpa*
NE-214	*P. deltoides* x *P. trichocarpa*
NE-216	*P. deltoides* x *P. trichocarpa*
NE-222	*P. deltoides* x *P. nigra* var. *caudina*
NE-223	*P. deltoides* x *P. nigra* var. *caudina*
NE-224	*P. deltoides* x *P. nigra* var. *caudina*
NE-225	*P. deltoides* x *P. nigra* var. *caudina*
NE-235	*P. deltoides* x *P. nigra* 'Incrassata'
NE-238	*P. deltoides* var. *angulata* 'Volga'

Appendix I continued

Clone	Parentage
NE-250	P. deltoides var. angulata x P. trichocarpa
NE-252	P. deltoides var. angulata x P. trichocarpa
NE-253	P. deltoides var. angulata x P. trichocarpa
NE-255	P. deltoides var. angulata x P. trichocarpa
NE-259	P. deltoides var. angulata x P. nigra 'Incrassata'
NE-264	P. deltoides var. angulata x P. nigra 'Volga'
NE-265	P. deltoides var. angulata x P. nigra 'Volga'
NE-274	P. deltoides var. occidentalis x P. simonii
NE-279	P. nigra x P. laurifolia
NE-280	P. nigra x P. laurifolia
NE-289	P. 'Baatanicorum vitrum' x P. nigra 'Volga'
NE-292	P. 'Baatanicorum vitrum' x P. trichocarpa
NE-293	P. nigra var. betulifolia x P. nigra 'Volga'
NE-294	P. nigra var. betulifolia x P. nigra 'Volga'
NE-295	P. nigra var. betulifolia x P. nigra 'Volga'
NE-296	P. nigra var. betulifolia x P. trichocarpa
NE-298	P. nigra var. betulifolia x P. trichocarpa
NE-299	P. nigra var. betulifolia x P. trichocarpa
NE-300	P. nigra var. betulifolia x P. trichocarpa
NE-301	P. nigra var. betulifolia x P. trichocarpa
NE-302	P. nigra var. betulifolia x P. trichocarpa
NE-303	P. nigra var. charkowiensis x P. nigra var. plantierensis
NE-308	P. nigra var. charkowiensis x P. nigra 'Incrassata'
NE-310	P. nigra var. charkowiensis x P. nigra var. caudina
NE-313	P. nigra var. charkowiensis x P. nigra var. caudina
NE-314	P. nigra var. charkowiensis x P. nigra var. caudina
NE-316	P. nigra var. charkowiensis x (P. x euramericana 'Robusta')
NE-318	P. nigra var. charkowiensis x P. deltoides
NE-320	P. nigra var. charkowiensis x P. trichocarpa

Appendix I continued

Clone	Parentage
NE-321	*P. nigra* var. *charkowiensis* x *P. trichocarpa*
NE-322	*P. nigra* var. *charkowiensis* x *P. trichocarpa*
NE-323	*P. nigra* var. *charkowiensis* x *P. trichocarpa*
NE-325	*P. balsamifera* var. *candicans* x (*P.* x *berolinensis*)
NE-327	*P. balsamifera* var. *candicans* x (*P.* x *berolinensis*)
NE-338	(*P.* x *petrowskyana*) x *P. nigra* var. *caudina*
NE-341	(*P.* x *rasumowskyana*) x *P. nigra* var. *plantierensis*
NE-343	*P. nigra* x *P. laurifolia*
NE-344	*P. deltoides* x *P. grandidentata*
NE-345	*P. deltoides* x *P. trichocarpa*
NE-346	*P. deltoides* x *P. trichocarpa*
NE-347	*P. deltoides* x *P. trichocarpa*
NE-348	*P. deltoides* x *P. trichocarpa*
NE-350	*P. deltoides* x *P. trichocarpa*
NE-351	*P. deltoides* x *P. nigra* var. *caudina*
NE-353	*P. deltoides* x *P. nigra* var. *caudina*
NE-357	*P. deltoides* x *P. nigra* var. *caudina*
NE-359	*P. deltoides* x *P. nigra* var. *caudina*
NE-360	*P. deltoides* x *P. nigra* var. *caudina*
NE-366	*P. deltoides* x *P. nigra* var. *caudina*
NE-367	*P. deltoides* x *P. nigra* var. *caudina*
NE-372	*P. deltoides* var. *angulata* x *P. trichocarpa*
NE-373	*P. deltoides* var. *angulata* x *P. trichocarpa*
NE-374	*P. deltoides* var. *angulata* x *P. trichocarpa*
NE-375	*P. deltoides* var. *angulata* x *P. nigra* var. *plantierensis*
NE-376	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*
NE-378	*P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina*
NE-383	*P. nigra* var. *betulifolia* x *P. trichocarpa*
NE-385	*P. simonii* x (*P.* x *berolinensis*)

Appendix I continued

Clone	Parentage
NE-386	P. 'Candicana' x (P. x berolinensis)
NE-387	P. 'Candicana' x (P. x berolinensis)
NE-388	P. maximowiczii x P. trichocarpa
NE-389	P. deltoides x P. nigra var. caudina
NE-396	
AK-30	P. alba, Brampton (A 69) x glandulosa, Korea (gl.1)
C-147	P. canescens
CAG-23	P. canescens, Czechoslovakia (C 18) x (alba x grandidentata) Toronto (AG 7)
CAG-77	P. canescens, Czechoslovakia (C 18) x (alba x grandidentata) Toronto (AG 7)
D-38	P. deltoides
D-51	P. deltoides
DN-1	P. euramericana 'Alenstein'
DN-2	P. euramericana 'Baden'
DN-3	P. euramericana 'Dolomiten'
DN-4	
DN-5	P. euramericana 'Gelrica'
DN-7	P. euramericana 'Heidemij'
DN-9	P. euramericana 'Lons'
DN-14	P. x euramericana 'Harff'
DN-15	P. x euramericana 'Regenere d'Auge'
DN-16	P. x euramericana 'Regenere Batard d' Hauterive'
DN-17	P. x euramericana 'Robusta'
DN-18	P. x euramericana 'Tardif de Champagne'
DN-19	P. x euramericana 'Blanc du Poitou'
DN-20	P. x euramericana 'I-61/59'
DN-21	P. x euramericana 'Jacometti'
DN-22	P. x euramericana 'I-262'

Appendix I continued

Clone	Parentage
DN-23	_P._ x _euramericana_ 'I-106/56'
DN-25	_P._ x _euramericana_ 'I-55/56'
DN-26	_P._ x _euramericana_ 'B-56'
DN-28	_P._ x _euramericana_ 'Ostia'
DN-29	_P._ x _euramericana_ 'Chopa de Santa Fe'
DN-30	_P._ x _euramericana_ 'Canada Blanc'
DN-31	_P._ x _euramericana_ 'Negrito de Granda'
DN-34	_P._ x _euramericana_ 'Eugenei'
DN-55	_P._ x _euramericana_
DN-70	_P._ x _euramericana_
DN-96	
IH-45/51	_P._ _euramericana_
IH-65A	_P._ _euramericana_
IH-214	_P._ _euramericana_
JAC-7	_P._ x _jackii_
GA-87	_P._ _grandidentata_ x _alba_ (G X A 321)
GA-88	_P._ _grandidentata_ x _alba_ (G X A 321)
WIS-5	_P._ x _euramericana_ 'Wisconsin #5'
WIS-131	_P._ x _euramericana_
Milarch Rd.	_P._ x _euramericana_ 'Eugenei'
Raverdeau	_P._ x _euramericana_ Raverdeau
NC-5258	_Populus_ spp.
NC-5260	_P._ _tristis_ x _P._ _balsamifera_ 'Tristis #1'
NC-5339	_P._ _alba_ x _P._ _grandidentata_ 'Crandon'
NC-5351	_Populus_ spp.

Appendix II. PCA's 1979 hybrid poplar clonal trial planting map, Mason County, MI

Clonal trial plantings — Rep. #1

Row no.	1st	2nd	3rd	4th	5th
1.	NE-206	NE-58	NE-348	NE-389	NE-235
2.	DN-28	NE-48	NE-274	NE-47	NE-1
3.	NE-387	Norway	5258	NE-255	NE-298
4.	NE-299	NE-252	NE-300	D-51	L-296
5.	NE-351	NE-16	L-239	NE-19	NE-238
6.	I45/51	NE-386	NE-41	NE-225	NE-316
7.	NE-346	NE-224	NE-214	NE-264	L-316
8.	WIS. 5	NE-32	NE-318	DN-17A	DN-34
9.	DN-30	NE-20	NE-238	NE-373	WIS. 131
10.	NE-253	5351	NE-209	DN-31	NE-375
11.	NE-50	NE-207	NE-265	DN-17B	NE-359
12.	DN-18	NE-308	Raverdeau	NE-353	Tristis

Clonal trial plantings — Rep. #2

Row no.	1st	2nd	3rd	4th	5th
1.	NE-386	DN-28	NE-351	NE-252	NE-373
2.	NE-32	NE-274	NE-348	DN-17A	NE-308
3.	DN-18	NE-50	L-316	NE-41	NE-1
4.	NE-318	D-51	NE-265	NE-346	NE-235
5.	NE-58	L-296	DN-17B	DN-30	NE-387
6.	NE-253	NE224	NE-298	NE-299	NE-375

Appendix II continued

Row no.	Clonal trial plantings			Rep. #2
	1st	2nd	3rd	4th	5th

Row no.	1st	2nd	3rd	4th	5th
7.	Norway	NE-214	NE-2251	DN-31	NE-316
8.	NE-47	5351	NE-359	NE-20	NE-48
9.	Raverdeau	NE-255	WIS. 5	5258	NE-388
10.	NE-16	NE-389	NE-19	DN-34	L-239
11.	WIS.	NE-300	NE-207	NE-206	I45/51
12.	NE-264	NE-238	NE-209	NE-353	Tristi

Row no. — Clonal trial plantings — Rep. #3

Row no.	1st	2nd	3rd	4th	5th
1.	NE-1	NE-348	NE-373	NE-224	NE-47
2.	NE-20	NE-351	DN-28	L-296	5258
3.	NE-32	NE-387	5351	NE-300	L-316
4.	I45/51	NE-308	NE-252	Norway	NE-265
5.	DN-30	NE-19	NE-298	NE-359	NE-16
6.	NE-346	NE-238	NE-214	NE-235	NE-386
7.	NE-264	DN-34	NE-207	NE-388	NE-253
8.	DN-18	WIS. 131	NE-389	NE-225	NE-255
9.	DN-17B	NE-299	NE-318	WIS. 5	L-239
10.	NE-209	NE-274	NE-50	DN-31	DN-17A
11.	NE-206	NE-58	NE-48	Raverdeau	NE-375
12.	NE-41	NE-316	D-51	NE-353	Tristis

Appendix III. PCA's 1980 hybrid poplar clonal trial planting map, Mason County, MI

Row no.	Clonal trial plantings			Rep. #1
	1st	2nd	3rd	4th	5th

Row no.	1st	2nd	3rd	4th	5th
1.	NE-206	NE-58	NE-348	NE-389	NE-235
2.	DN-28	NE-48	NE-274	DBJ-2-2	NE-1
3.	NE-387	GRJ-6	5258	NE-255	NE-298
4.	NE-299	NE-252	NE-300	D-51	NE-296
5.	NE-351	NE-16	DBJ-2-1	NE-19	NE-238
6.	I45/51	NE-386	NE-41	NE-225	NE-316
7.	NE-346	NE-224	NE-214	NE-264	LUJ-7
8.	WIS. 5	NE-32	NE-318	DN-17	DN-34
9.	DN-30	NE-20	NE-388	NE-373	WIS. 131
10.	NE-253	NE-51	NE-209	DN-31	NE-375
11.	NE-50	NE-207	NE-265	DN-21	NE-359
12.	DN-18	NE-308	Raverdeau	NE-353	LJ-14
13.	NE-205	NE-374	NE-367	NE-278	NE-366
14.	DN-12-65	DN-38-69	DN-35-69	DN-4-62	

Appendix III continued

Row no.	Clonal trial plantings				Rep. #2
	1st	2nd	3rd	4th	5th
1.	NE-386	DN-28	NE-351	NE-252	NE-373
2.	NE-32	NE-274	NE-348	DN-17	NE-308
3.	DN-18	NE-50	LUJ-7	NE-41	NE-1
4.	NE-318	D-51	NE-265	NE-346	NE-235
5.	NE-58	NE-296	DN-21	DN-30	NE-387
6.	NE-253	NE-224	NE-298	NE-299	NE-375
7.	GRJ-6	NE-214	NE-225	DN-31	NE-316
8.	DBJ-2-2	NE-51	NE-359	NE-20	NE-48
9.	Raverdeau	NE-255	WIS. 5	5258	NE-388
10.	NE-16	NE-389	NE-19	DN-34	DBJ-2-1
11.	WIS. 131	NE-300	NE-207	NE-206	I45/51
12.	NE-264	NE-238	NE-209	NE-353	LJ-14
13.	NE-367	NE-366	NE-374	NE-205	NE-278
14.	DN-38-69	DN-35-69	DN-4-62	D-12-62	

Appendix III continued

Row no.		Clonal trial plantings			Rep. #3
1.	NE-1	NE-348	NE-373	NE-224	DBJ-2-2
2.	NE-20	NE-351	DN-28	NE-296	5258
3.	NE-32	NE-387	NE-51	NE-300	LUJ-7
4.	I45/51	NE-308	NE-252	GRJ-6	NE-265
5.	DN-30	NE-19	NE-298	NE-359	NE-16
6.	NE-346	NE-238	NE-214	NE-235	NE-386
7.	NE-264	DN-34	NE-207	NE-388	NE-253
8.	DN-18	WIS. 131	NE-389	NE-225	NE-255
9.	DN-21	NE-299	NE-318	WIS. 5	DBJ-2-1
10.	NE-209	NE-274	NE-50	DN-31	DN-17
11.	NE-206	NE-17	NE-48	Raverdeau	NE-375
12.	NE-41	NE-316	D-51	NE-353	LJ-14
13.	NE-374	NE-278	NE-366	NE-205	NE-367
14.	D-12-65	DN-38-69	DN-35-69	DN-4-62	

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