MYCORRHIZAE OF POPLARS[1]

R. C. Schultz
J. G. Isebrands
P. P. Kormanik[2]

Abstract. Poplar hybrids, being screened for short-rotation intensive culture, can form ecto-, endo-, or ectendo-mycorrhizae or may be autotrophic. Different sections of the genus Populus tend to be selective in the type of mycorrhizae formed. Knowledge of which types are formed influences the kinds of propagule production, site preparation, and herbicide techniques that should be used in establishing poplar plantations.

INTRODUCTION

Since 1970, the North Central Forest Experiment Station at Rhinelander, Wisconsin, has been screening Populus clones on the basis of their growth potential for short-rotation intensive culture (SRIC). Specific studies have been conducted on the relationship between morphological and physiological variables and the quantity and quality of yield for selected clones. However, a better understanding of the physiological interactions in the root zone of SRIC poplars is needed to improve cultural practices and yields. One of the most important interactions in the root zone is the symbiosis between roots and fungi called mycorrhizae. This research was conducted to describe the importance of mycorrhizae to the establishment and growth of Populus trees.

With few exceptions, all plants in nature develop mycorrhizae to various degrees. Wilhelm (1966) states that, under field conditions, plants do not, strictly speaking, have roots, but rather, mycorrhizae. Mycorrhizae have been shown to improve the growth of trees through their influence on nutrient and water uptake, disease resistance, high temperature tolerance, and hormone interactions. However, most of the major research efforts reported in the literature to date have been on nutrient-uptake interactions. The two major types of mycorrhizae most frequently encountered are "ectomycorrhizae" and "endomycorrhizae." A third type, "ectendomycorrhizae," is less frequently encountered and poorly understood.

Ectomycorrhizae

Ectomycorrhizal infection is initiated from spores or hyphae (collectively referred to as "propagules") of certain fungal symbionts in the rhizosphere of feeder roots. These propagules are stimulated by root exudates and grow vegetatively over the feeder-root surface, forming the external fungal mantle. After mantle development, hyphae develop intercellularly in the root cortex, forming the "Hartig-net," which may completely replace the middle lamellae between cortical cells. This Hartig-net is the major diagnostic feature of ectomycorrhizae. Ectomycorrhizae may appear either as simple unforked roots, bifurcate roots, multiforked

[1]Journal Paper No. J-10984 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Projects No. 2523 and 2524.

[2]Authors are Professor, Forestry Department, Iowa State University, Ames, Iowa 50011; Wood Scientist, Forestry Sciences Laboratory, North Central Forest Experiment Station, Rhinelander, Wisconsin 54501; and Principal Silviculturalist, Institute for Mycorrhizal Research and Development (IMRD), Southeastern Forest Experiment Station, Athens, Georgia 30602.

roots, or even nodular-like roots that are readily visible to the naked eye. The visible structures are commonly referred to as "short roots." Each individual short root, regardless of branching pattern, is an ectomycorrhiza. Individual hypha, multiple hyphae, or rhizomorphs may radiate into the soil from the fungus mantles on short roots and eventually unite with the base of fruiting bodies of the fungus (Marx, 1975; Smith, 1980).

It is estimated that more than 2100 species of ectomycorrhizal fungi exist on trees in North America. Most fungi that form ectomycorrhizae with forest trees are Basidiomycetes that produce mushrooms or puffballs as reproductive structures. However, certain of the Ascomycetes, such as truffles, also are symbiotic. The fruiting bodies of these fungi produce millions of spores that are widely disseminated by wind and water. Moreover, most ectomycorrhizal fungi are dependent on their tree hosts for essential carbohydrates, amino acids, vitamins, etc., needed to complete their life cycle. Thus, ectomycorrhizal development with a host is usually a prerequisite for fruiting-body production by these fungi.

Under normal forest conditions, many species of fungi may be involved in the ectomycorrhizal associations of a forest, a single tree species, an individual tree, or even a small segment of lateral root. Indeed, as many as three species of fungi have been isolated from an individual ectomycorrhiza (Marx, 1975). A single species of fungus may also enter into ectomycorrhizal association with numerous tree species. Some of the fungi may be rather host specific, but little work has been done on this phenomenon.

Ectomycorrhizae occur naturally on many of the important forest tree species of the world. All members of the gymnosperm family Pinaceae are ectomycorrhizal; i.e., Pinus (pine), Picea (spruce), Abies (fir), Larix (larch), Tsuga (hemlock), and Pseudotsuga (Douglas-fir), as well as certain angiosperms such as Salix (willow), Populus (aspen), Carya (hickory and pecan), Quercus (oak), and Fagus (beech).

Endomycorrhizae

Endomycorrhizal fungi, commonly referred to as the "vesicular-arbuscular" fungi, are the most widespread and important root symbionts. They are not restricted to specific groups of plants, but occur in practically all families of angiosperms, gymnosperms, and many pteridophytes and byrophytes. Most of the economically important grain and forage crops, as well as the major berry crops and fruit and nut trees, normally form endomycorrhizae. Many of our most important forest trees, such as Liquidambar (sweetgum), Platanus (sycamore), Ulmus (elm), Juglans (walnut), Fraxinus (ash), Liriodendron (yellow poplar), and Populus (cottonwood), form endomycorrhizae. Although endomycorrhizal fungi can form a loose network of hyphae on feeder-root surfaces, they do not develop the dense fungal mantle found on the ectomycorrhizae. Instead, endomycorrhizal fungi form large, conspicuous, thick-walled spores on the root surfaces, in the rhizosphere, and sometimes in feeder-root tissues. Endomycorrhizal fungal hyphae penetrate the cell walls of the epidermis and subsequently grow into the cortical cells of the root. Once in the cortical cells, these infective hyphae may develop specialized absorbing or nutrient-exchanging structures called "arbuscules." Arbuscules consist of dense clusters of very fine dichotomously branched filaments that may occupy the entire lumen of the cell. Vesicles develop later, generally in the middle and outer cortex, and appear as terminal swellings either within or between cells. No external morphological changes occur in roots infected with endomycorrhizal fungi, although with some hosts, a yellow or brown color in the roots has been reported. Endomycorrhizal fungi rarely invade meristematic tissue. Many conflicting opinions have been expressed about the functions of the arbuscules. Generally, vesicles are regarded as temporary storage organs for the fungus, and arbuscules as the exchange sites between the fungus and the host cell.

The fungi that form endomycorrhizae are mainly Phycomycetes. They do not produce large, above-ground fruiting bodies or wind-disseminated spores as most ectomycorrhizal fungi do. Some of them produce large azygospores and chlamydospores on or in the roots, whereas others produce large sporocarps (5 to 10 mm diam.) containing many spores. Spread of of these fungi in soils is by root contact, moving water, insects, or animals. In the absence of a host, the spores of these fungi are still able to survive in the soil for many years. As with ectomycorrhizal fungus spores, endomycorrhizal spores apparently are stimulated to germinate by root exudates in the rhizosphere.

Ectendomycorrhizae

Ectendomycorrhizae have some of the features of both ecto- and endo-mycorrhizae. They have a limited occurrence and, with regard to forest trees, are found primarily on roots of ectomycorrhizal trees. However,

very little is known about the species of fungi involved or their importance to the growth of trees because little research has been done on them.

Poplar Mycorrhizae

Relatively little is known about poplar mycorrhizae. Walker (1980) made a detailed survey of the literature concerning the mycorrhizae of Populus. He listed all assumed or proven mycorrhizal fungal associates with Populus species (Table 1). Twenty poplar species were shown to be mycorrhizal and all or any of the three major types of mycorrhizae; ecto-, endo-, and/or ectendo-mycorrhizae may be present. Eight poplar species are also shown to be capable of autotrophic growth without mycorrhizae. Poplars can be mycotrophic or autotrophic, depending on age and environmental conditions (Dominik, 1956, 1958). This ability is seen as an advantage for pioneer species that usually become established on drastically altered sites where mycorrhizal fungal inoculum may not be readily available.

Very little work has been done on the ecology and physiology of mycorrhizal poplars. However, Walker and McNabb (1983) recently assessed growth differences and mycorrhizal conditions of seven clones of poplar that were grown from rooted cuttings in five different unsterilized Iowa soils for 1 year in a greenhouse. Four of the soils were from central Iowa, and the fifth was from northeastern Iowa. Two of the soils were from woodland sites where Populus grandidentata Michx. was the major tree species, and one soil from an oak-hickory-elm woodland where Populus spp. were absent. The other two soils were from agricultural sites (corn-soybean fields). One of these soils had received frequent fertilizer and herbicide applications while the other had never been treated with agricultural chemicals. The seven clones used are given in Table 2. All three major types of mycorrhiza were found in the genus Populus. Their results also suggest that there may be differences in mycorrhizal development between the different sections of Populus. NC-5260 (North Central Forest Experiment Station (NC) number 5260), of the Tacamahaca group, seemed able to form any of the three types of mycorrhizae. NC-5339, of the Leuce group formed ecto- and ectendo-mycorrhizae, but formed only a few endomycorrhizae. The P. euramericana clones, of the Aigeiros group, formed many endomycorrhizae but did not form either of the other two mycorrhizae.

In another study, Walker et al., (1982) planted four clones of hybrid poplars at two locations in central Iowa to investigate the development of mycorrhizae over time and the changes in their populations in the soil. The four clones used were four of the same ones used in the previous study; namely, NC-5260, NC-5323, NC-5326, NC-5339. One of the sites was a sandy terrace near the Des Moines River, well above flood level. This site was occupied by poorly growing white ash (Fraxinus americana L.). The second site was meadow land on a silt-loam soil in the floodplain of a small stream that occasionally flooded. Vegetation on this site consisted of a mixture of grasses, smooth brome (Bromus inermis Leyss.), and foxtail (Setaria spp.). Both sites were tilled, and then rooted cuttings were planted. During the growing season, cuttings were periodically excavated, and plant root and rhizosphere soil samples collected.

A total of 15 species of endomycorrhizae were found on the two sites (Table 3). Ten of those were found at the first site, and 12 at the second site. This diversity was greater than the 3 to 5 species per site that have been commonly reported in the literature. Walker et al. (1982) suggest that these numbers were not unrealistic, but, rather, the result of more intensive and careful sampling. The spatial distribution of species spores were usually unevenly grouped over the site. This grouping was thought to be related to association of fungi to previous vegetation distribution. No differences were found in spore numbers related to clones, suggesting that clones either had no effect or had similar effects on spore production. There was little mycorrhizal development on the poplar roots despite large numbers of spores in the soil. This supports the idea that the trees had little influence on the spore populations. Spore numbers in the soil tended to be least in spring and greatest in late summer and early autumn. These differences might be directly or indirectly related to soil moisture conditions. Plowing and herbicide application could depress spore production. Walker et al. (1982) concluded that, although there are large numbers of spores available on many sites, a knowledge of the fungal species and their diversity, distribution, and population levels would be useful in determining site preparation and planting strategies for poplar plantations.

Table 1. Mycorrhizal status of poplars surveyed for mycorrhizae by Walker (1980). (+ = present; - = absent; blank = no data.)

Genus section and poplar species[a]	ect[b]	ecten[b]	end[b]	aut[b]
Leuce				
P. alba	+		+	+
P. canescens	+			
Aigeiros x Leuce				
P. nigra x *alba*	-		+	-
Aigeros				
P. deltoides	+		+	+
P. x *euramericana*	+	+	+	+
P. fremontii S. Wats.	+		-	
P. x *marilandica*	+		+	-
P. nigra	+		+	-
P. regenerata Henry	+		-	-
Tacamahaca x Aigeiros				
P. x *berolinensis*	+		+	-
(Tacamahaca x Aigeiros) x Aigeiros				
P. x *generosa* Henry x *nigra*	+		+	
Tacamahaca				
P. angustifolia	+			
P. balsamifera	+			
P. candicans Aiton	+		-	-
P. trichocarpa	+			
Leucoides				
P. heterophylla L.	-		-	+
Tremulae				
P. grandidentata Michx	+		-	
P. tremula	+	+	+	-
P. tremuloides	+		+	
Tremula x Aigeiros				
P. tremula x *P.* x *euramericana*	+		-	-

[a] Includes varieties and subspecies.

[b] ect = ectomycorrhizal; ecten = ectendomycorrhizal; end = endomycorrhizal; aut = autotrophic.

Table 2. Overall mean mycorrhizal colonization levels for seven poplar clones grown for a year in a greenhouse in five Iowan soils. Minimum = 0, maximum = 3. Endo = endomycorrhiza, Ecto = ectomycorrhiza, Ecten = ectendomycorrhiza (Walker and McNabb, 1983).

Clone	Parentage of clone	Genus section	Endo	Thin-mantled Ecto	Ecten
NC-5260	P. tristis x P. balsamifera	Tacamahaca	2.12	0.08	0.36
NC-5323	P. x euramericana	Aigeiros	2.04	0	0
NC-5326	P. x euramericana	Aigeiros	1.80	0	0
NC-5328	P. x euramericana	Aigeiros	1.96	0	0
NC-5377	P. x euramericana	Aigeiros	1.80	0	0
NC-5339	P. alba x P. grandidentata	Leuce x Tremulae	0.24**[a]	0.48	0.44

[a] **Significantly lower than others in the same column (p = 0.01).

In this paper, we also report the results of a study on the mycorrhizal condition and growth of two SRIC poplar clones in the establishment year. The objective of this study was to determine whether two diverse Populus hybrids become ecto- or endo-mycorrhizal, or remain autotrophic when grown in soils inoculated with an ectomycorrhizal or endomycorrhizal fungus or with natural inoculum.

METHODS

The study was conducted at the North Central Forest Experiment Station's Harshaw Experimental Farm near Rhinelander, Wisconsin, during the summer of 1980. The two Populus clones used in the study were Populus Tristis Fisch. x P. balsamifera L. cv. 'Tristis #1' (NC-5260) and Populus euramericana (Dode) Guinier cv. Eugenii (NC-5326). The hardwood cuttings used for the study were collected from a cutting orchard at the farm and were approximately 25 cm long.

The mycorrhizal fungi used were produced at the IMRD. The ectomycorrhizal fungus was Pisolithus tinctorius (PT) grown in pure culture by the techniques of Marx and Bryan (1975). The endomycorrhizal fungus was Glomus fasiculatus (GF) produced by growing the fungus in sorghum (Sorghum vulgare (Stapf.) Haines var. roxburghii) pot cultures. The soil and roots of these pot cultures were

Table 3. Species of endomycorrhizae found in surveys of soil collections made at two field sites in central Iowa. (Walker and McNabb, 1983b.)

Fungal species on the sandy terrace	Fungal species on the silt-loam flood plain soil.
ACAULOSPORA spp.	
A. scrobiculata Trappe	A. scrobilculata
A. spinosa Walker & Trappe sp. ined.	A. spinosa
	A. trappei Ames & Linderman
GIGASPORA spp.	
Gi. calospora (Nicol. & Gerd.) Gerd. & Trappe	Gi. calospora
Gi. gilmorei Trappe & Gerdmann	Gi. gilmorei
Gi. rosea Nicolson & Schenk	
Gi. heterogama (Nicol. & Gerd.) Gerd. & Trappe	
GLOMUS spp.	
	Gl. albidus Walker & Rhodes sp. ined.
Gl. constrictus Trappe	
	Gl. epigaeus Daniels & Trappe
Gl. fasciculatus (Thaxter sensu Gerd.) Gerd. & Trappe	Gl. fasciculatus
Gl. geosporus (Nicol. & Gerd) Walker stat. ined.	Gl. geosporus[a]
	Gl. microcarpus Tul. & Tul.
Gl. mosseae (Nicol. & Gerd.) Gerd. & Trappe	Gl. mosseae
	Gl. occultus sp. ined.

[a] = Glomus macrocarpus var. geosporus (Nicolson & Gerdemann) Gerdemann & Trappe.

used as inoculum. The natural inoculum consisted of unidentified fungal symbionts contained in the unfumigated soil from the farm. The soil was a sandy loam with the following chemical analysis: 35mg/l Bray 1 extractable P, 237mg/l total P, 323mg/l total Kjeldahl nitrogen, 14mg/l extractable NO_3-N, 68mg/l K, 160mg/l Ca, 619mg/l, Al, 71mg/l Fe, a pH of 5.3, and 1.04% organic matter. The soil was fumigated with methyl bromide (Dowfume MC-2, Dow Chemical Co., Midland, MI 48604)[3] at a rate of 450g per 12m2 of soil surface (15cm deep).

The study was conducted in 1m x 1m x 1m wooden boxes similar to those used in numerous previous studies (Kormanik et al., 1981, 1982; Schultz et al., 1981, 1982). The bottoms of the boxes were filled with approximately 15cm of coarse gravel to facilitate drainage.

The study as a 2x4 factorial with 3 replications set up as a split plot in a randomized complete-block design. Whole-plot treatments consisted of either fumigated or unfumigated soils. Within the fumigated soils, there were three treatments. One was inoculated with PT at the rate of 1 liter per box (FPT), one was inoculated with GF at the rate of 1 liter per box (FGF), and one was left uninoculated (FC) as a control. The unfumigated soil (UF), with its natural inoculum, was the fourth treatment. Inoculum was mixed into the top 20cm of soil to allow contact with the full length of the cutting.

Soil pH was adjusted to 6.0 by adding hydrated lime ($Ca(OH)_2$) at the rate of 183g per box. No phosphorus or potassium fertilizer was added because low phospohrus was desired and potassium levels were sufficient for tree growth. A total of 1680kg/ha of NH_4NO_3 was added at eight equally spaced intervals throughout the study (21g/box, per addition).

Ten cuttings of each clone were planted in two adjacent rows in each box. Clones (subplots) were randomly assigned to the two sets of rows in each box. In the FPT treatment, five Jack pine (Pinus banksiana L.) were also planted to test the viability of the PT inoculum. PT is known to readily infect pine.

Growth responses to the treatments were measured twice during the study. The first measurement was done August 15, 1980. At that time, height, diameter, number of leaves, and leaf area were measured. The study was harvested October 15, 1980. In addition to these measurements, dry weights of the leaves, stems, cuttings, and roots were collected at this time. Ten percent of the fine feeder roots of each cutting were collected for mycorrhizal analysis. The endomycorrhizal roots were stained and analyzed according to a method of Kormanik et al. (1980). Ectomycorrhizal assays were made according to a method of Dr. Donald Marx of the IMRD (pers. commun.)

The data were analyzed by analysis of variance. Significant treatment differences were identified by use of the following orthogonal contrasts: 1) unfumigated vs. all the fumigated, 2) the fumigated control vs. fumigated inoculated, and 3) ectomycorrhizal vs. the endomycorrhizal treatment.

RESULTS AND DISCUSSION

Treatment Responses

There were no height growth differences among treatments at either of the two measurement dates (Table 4). It is possible that the large carbohydrate reserve in the cuttings may have been responsible for the lack of response. A two or more year study probably would be necessary to describe these treatment differences. On the other hand, it is possible that competition resulting from the close spacing of the cuttings in the boxes resulted in the similar height-growth responses among all treatments. Preferential allocation of photosynthates to stem elongation reduced the carbohydrates available for biomass production and diameter growth in some treatments.

There were no differences among treatments in the August measurement of cutting diameters (Table 4). By the middle of October, however, the cuttings growing in the UF soil had a significantly smaller diameter than those growing in any of the fumigated treatments (Table 5). These differences may be the result of a greater and more diverse

[3]Use of trade names is for convenience of the reader and does not constitute an endorsement by the USDA Forest Service.

Table 4. First season growth data for Tristis (NC-5260) and Eugenei (NC-5326) cuttings rooted under the following soil treatments: 1) fumigated soils that were a] inoculated with an endomycorrhizal fungus (FEN), or b] inoculated with an ectomycorrhizal fungus (FEC), or c] uninoculated (FC); or, 2) unfumigated soils with natural inoculum.

	Height (m)	Diameter (cm)	Number of leaves	Leaf area (cm^2)	Height (m)	Diameter (cm)
Clone						
NC-5260	0.88	0.86	45	5867	0.88	0.90
NC-5326	0.74	0.73	39	5674	0.92	0.95
Treatment						
UF	0.80	0.78	33	5474	0.86	0.88
FC	0.83	0.82	46	5918	0.94	0.96
FGF	0.81	0.81	41	5734	0.90	0.95
FPT	0.79	0.79	47	5958	0.89	0.92
Significance[a]						
Clone	**	**	**	--	--	*
Treatment	--	--	**	--	--	*
Contrasts[b]						
UF vs. all	--	--	*	*	--	*
FC vs. FEN, FEC	--	--	--	--	--	--
FEN vs. FEC	--	--	*	--	--	--

[a] Significant F values; **(.01); *(.05).

[b] Orthogonal contrasts; **=.01; *=.05.

24

Table 5. October biomass for Tristis (NC-5260) and Eugenei (NC-5326) cuttings rooted under the following soil treatments: 1) fumigated soils that were a] inoculated with an endomycorrhizal fungus (FEN), b] inoculated with an ectomycorrhizal fungus (FEC), or c] uninoculated (FC); or, 2) unfumigated soils with natural inoculum (UF).

	Hardwood Cutting Dry Weight (g)	New Stem Material Dry Weight (g)	Root Dry Weight (g)	Total Dry Weight Minus Leaf Weights (g)
Clone				
NC-5260	11.8	16.4	11.3	39.5
NC-5326	10.2	18.4	7.4	35.2
Treatment				
UF	10.8	14.9	8.7	34.1
FC	11.2	18.9	9.5	39.8
FGF	10.7	16.7	8.7	35.5
FPT	11.4	18.4	10.3	40.0
Significance[a]				
Clone	*	--	*	*
Treatment	--	*	*	*
Contrasts[b]				
UF vs. all	--	*	*	*
FC vs. FGF, FPT	--	*	--	--
FGF vs. FPT	--	*	*	*

[a]Significant F values; * = .05.

[b]Orthogonal comparisons; * = .05.

25

population of microorganisms in the UF soil, which put a greater symbiotic and pathological demand on the cuttings. There may also have been a competition effect from the weeds growing in the boxes. A similar response was observed for stem and root dry weights. Fumigation increased growth by 8 to 30%. The FGF treatment produced the second smallest trees, and there was little difference between the FPT- and FC-treatment trees. This result is evidence that the ectomycorrhizal development had no biological impact on the trees. As seen in other studies, smaller trees for the mycorrhizal treatments are the common occurrence under moderate to high phosphorus fertility. We believe this phenomenon is due to the preferential reallocation of photosynthates from the tops to the roots during the establishment of the mycorrhizal symbiosis.

Clonal Responses

'Tristis' grew rapidly early in the season, whereas 'Eugenei' put on extensive growth later in the growing season. At the August 15th measurement date, Tristis had put on significantly more height and diameter growth than Eugenei. However, by October 15th, Eugenei had equalled and surpassed the height growth and put on significantly more diameter growth than Tristis. For the most part, Tristis had put on all its growth by August 15, although there was a small amount of growth after that date.

Eugenei's growth continued over the whole growing season. When compared with Tristis, it retained its leaves for a much longer time. Although Tristis had significantly more leaves than Eugenei on August 15th, there was no difference in the total leaf area between the two clones because Eugenei's leaves were larger. By October 15th, Tristis had shed all its leaves while Eugenei still retained some near the top of the shoot. The parents of Tristis come from more northerly latitudes than Eugenei. Perhaps this is why Tristis is more sensitive to the early shortening of the seasonal photoperiod.

In terms of total biomass response, Tristis outgrew Eugenei (Table 5). Although the hardwood cutting weights at the end of the study were slightly heavier for Tristis, there was no difference in new stem growth produced on the cuttings. Leaf dry-weight comparisons could not be made because of our sample dates, but it seems likely that there was little difference in total mass of leaves produced by either clone. The major difference between clones in biomass occurred in root growth. The average Tristis tree produced almost 4g more root dry weight than did Eugenei. This response is of special interest when comparing the mycorrhizal responses of the two clones during the establishment year.

Mycorrhizal Responses

Eugenei trees produced more ecto- and endo-mycorrhizae than did Tristis (Table 6). For example, Eugenei had 63% of its fine roots infected in the FGF treatment and 52% in the UF treatment. This infection compares with 23% and 39% respectively, for Tristis. The observed infections suggest that Eugenei had a greater affinity for GF than for the native fungi in the UF treatment, whereas the reverse is the case for Tristis. The larger root system of Tristis also suggests that this clone exploited the soil profile more completely and therefore did not gain the same advantages from the mycorrhizal symbiosis than did Eugenei with its smaller root system. The ectomycorrhizal response of the two clones was not as clear. Upon close examination, only one site of ectomycorrhizal infection was found on any of the root samples. Fifty-seven percent of the Eugenei trees had one infection site, compared with 43% of the Tristis trees. Even for the ectomycorrhizal case, Eugenei had a greater percentage of trees infected than did Tristis. It seems that the minimal ectomycorrhizal infection had no biologically significant impact on the cuttings. However, ectomycorrhizal plants were generally 10 to 15% heavier than were endomycorrhizal plants. This growth difference probably is not the result of PT stimulation, but, rather, a lack of response to the symbiosis.

The results of this study are similar to those found in other experiments. Both clones will form endomycorrhizae, but both also seem to be capable of autotrophic growth. It seems that, under the phosphorus levels of this study (35mg/l Bray 1 extractable P), the trees do not form many mycorrhizae. However, at similar phosphorus levels, many other species do form extensive mycorrhizal root systems (Schultz et al., 1982). Before it can be stated that these clones are definitely capable of autotrophic growth, growth comparisons at different phosphorus levels must be made. Although neither clone showed much development of ectomycorrhizae with PT, the literature suggests that Tristis may have a greater selectivity for ectomycorrhizal development than does Eugenei.

Table 6. Mycorrhizal development in Tristis (NC-5260) and Eugenei (NC-5326) cuttings rotted in unfumigated soils with natural inoculum or fumigated soils inoculated with endo- or ecto-mycorrhizal fungi.

	% of Roots Infected			% of Trees with 1 infection site
	Unfumigated		Fumigated	
Clone	Endo	Ecto	Endo	Fumigated-Ecto
NC-5260	39	0	23	43
NC-5326	52	0	63	57

CONCLUSIONS

Populus hybrids show extensive selectivity in mycorrhizal formation. This selectivity should be identified for the most important clones available so that proper inoculum can be used in producing propagules. In addition, cultural practices, such as site preparation and weed control with herbicides, can influence the available inoculum on a planting site. Although some hybrids seem to show autotrophic growth without mycorrhizal development at relatively low available soil phosphorus levels, the potential for mycorrhizal formation should be established for all hybrids.

ACKNOWLEDGMENT

The authors thank Marynell Redman and Paul Ehlers for their technical support on the study at the Harshaw farm.

LITERATURE CITED

Dominik, T. 1956. Projekt nowego podizialu mikoryz ektotroficiznych oparty na cechach morfologiczno-anatomicznych. (Tentative proposal for a new classification scheme of ectotrophic mycorrhizae established on morphological and anatomical characteristics.) Rocz. Nauk Lesn. 14:223-245. (English translation published by NSF and USDA OTS 60-21383. 1962).

Dominik, T. 1958. Studium nad miktrofizmen rodzaju Populus. (Study on mycotrophy of the genus Populus). Badawczy Lesn. Prace 1958. 181:117-172. (English translation in Study on mycotrophy of forest trees. National Science Foundation OTS 60-21227. 1964.)

Kormanik, P.P., W.C. Bryan, and R.C. Schultz. 1980. Procedure and equipment for staining large numbers of root samples for endomycorrhizal assay. Can. J. Microbiol. 26:536-538.

Kormanik, P.P., W.C. Bryan, and R.C. Schultz. 1981. Effects of three vesicular-arbuscular mycorrhizal fungi on sweetgum seedlings from nine mother trees. For. Sci. 27:327-335.

Kormanik, P.P., W.C. Bryan, and R.C. Schultz. 1982. The influences of vesicular-arbuscular mycorrhizae on growth and development of eight hardwood tree species. For. Sci. 28:531-539.

Marx, D.H. 1975. Mycorrhizae and establishment of trees on strip-mined land. Ohio J. Sci. 75:288-297.

Marx, D.H. and W.C. Bryan. 1975. Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soil infected with fungal symbionts. For. Sci. 21: 245-254.

Schultz, R.C., P.P. Kormanik, and W.C. Bryan. 1981. Effects of fertilization and vesicular-arbuscular mycorrhizal inoculation on growth of hardwood seedlings. Soil Sci. Soc. Am. J. 45:961-965.

Schultz, R.C. and P.P. Kormanik. 1982. Vesicular-arbuscular mycorrhizae and soil fertility influence mineral concentrations in seedlings of eight hardwood species. Can. J. For. Res. 12:829-834.

Smith, S.E. 1980. Mycorrhizas of autotrophic higher plants. Biol. Rev. 55:475-510.

Walker, C. 1980. Hybrid poplar mycorrhizae and endogenous spores in Iowa. Unpublished Ph.D. dissertation. Iowa State University, Ames, Iowa. Available from: University Microfilms, Ann Arbor, MI Order #80-10265.

Walker, C., C.W. Mize, and H.S. McNabb, Jr. 1982. Populations of endogonaceous fungi at two locations in Central Iowa. Can. J. Bot. 60:2518-2529.

Walker, C. and H.S. McNabb, Jr. 1983. Mycorrhizae and associated fungal spores in seven hybrid poplars potted in five Iowan soils. Can. J. Bot. (in press).

Wilhelm, S. 1966. Chemical treatments and inoculum potential of soils. Annu. Rev. Phytopathol. 4:53-78.