The Effects of Picloram (*Tordon* Series) and Line Maintenance on Ectomycorrhizal Fungi Associated with Spruce, *Picea mariana* (Mill.) B.S.P., Jack Pine, *Pinus banksiana* Lamb. and Tamarack, *Larix laricina* (Du Roi) Koch within Hydro Transmission Corridors of Manitoba

by

Suzanne M. Diamond

A Thesis presented to the University of Manitoba
in partial fulfillment of the requirements for the degree of
Masters of Science
in Botany

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THE EFFECTS OF PICLORAM (Tordon Series) AND LINE MAINTENANCE ON ECTOMYCORRHIZAL FUNGI ASSOCIATED WITH SPRUCE, Picea mariana (MILL.) B.S.P., JACK PINE, Pinus banksiana LAMB. AND TAMARACK, Larix laricina (DU ROI) KOCH WITHIN HYDRO TRANSMISSION CORRIDORS OF MANITOBA

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MASTER OF SCIENCE

Little things
are important
because they are little
we see them
but do not understand them.

Chief Dan George

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ABSTRACT

Effects of power line maintenance on mycorrhizal fungi associated with black spruce (*Picea mariana* (Mill.)B.S.P.), tamarack (*Larix laricina* (Du Roi) K. Koch) and jack pine (*Pinus banksiana* Lamb.) were studied at nine right-of-way (ROW) sites in north central Manitoba. Transmission corridors treated with *Tordon 101* and *Tordon 10K* at various times in the past (i.e. 1991, 1990, 1987, 1984, 1974) were chosen for study.

Analysis of variance (ANOVA) results comparing individual seedlings show that mean mycorrhizal levels within the ROW are between 20 - 50% lower than within the forest at most sites. Exceptions are at the ROW sites treated with *Tordon 10K* at Mafeking, Manitoba, were levels of mycorrhizal infestation seem to be enhanced. Although mycorrhizal levels are lower in sprayed ROW sites compared to unsprayed ROW sites, these differences are not significant in three out of the four cases studied. This suggests that the initial disturbance of the ROW from line clearance, along with related changes in the habitat, and not herbicide treatments with *Tordon 101*, are responsible for the reduced levels of mycorrhizae within the ROW sites.

Levels of mycorrhizal infestation after application of herbicides follow expected phenological patterns as mediated by seasonal affects. The significantly increased levels of infestation found within the ROW ten months after herbicide treatment with *Tordon 101*, may indicate a stimulatory effect of the spray treatment on mycorrhizae. If *Tordon 101* is enhancing fungal activity within the ROW, this will encourage conifer survival and is thus contrary to ROW management objectives. Phenological changes in mycorrhizal infestations, as affected by site parameters, soil factors and herbicide usage, are modelled.

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CHAPTER I

INTRODUCTION

Hydro ROW Management

Hydro right-of-way (ROW) corridors cover twenty-six thousand hectares of land in the province of Manitoba, spanning over ten thousand kilometers (Manitoba Hydro 1992). The vegetation beneath these lines must be maintained in order to prevent trees from exceeding six meters in height. Above this height interference with electro-magnetic fields around the lines occurs. Tree removal is necessary to minimize electrical conductance to ground, a problem which can lead to bystander electrocution, forest fire and loss of service.

Broadcast herbicides are generally used for tree control (McInnes 1989). Disturbance of ROW's from initial clearance, line construction, large vehicle traffic and vegetation management with herbicides has been shown to lead to altered species abundances of vascular and non-vascular plants (Magnusson 1986). In bog areas, soil erosion, loss of permafrost and an increased exposure of peat change the ROW habitat often in such a way that it is more supportive to target trees. Studies have shown that use of the herbicide picloram (4-amino-3,5,6-trichloropicolinic acid) results in the ecologically undesirable disappearance of *Sphagnum fuscum* and ericoid shrubs as well as an increased abundance of *Polytrichum strictum* (Magnusson and Stewart 1987).

Rationale for the study

This thesis looks at the effects of Picloram formulations on the mycorrhizal fungi associated with black spruce (*Picea mariana* (Mill.)B.S.P.), jack pine (*Pinus banksiana* Lamb.) and tamarack (*Larix laricina* (Du Roi) K. Koch). This topic was chosen because of the critical role that these fungi play in tree survival and succession at cleared sites (Perry et al. 1989). Ectomycorrhizal fungi, in particular, were chosen because of a relative lack of data on this topic and a need for understanding their importance for target tree establishment in Hydro ROW's within the boreal forests of Manitoba.

Analysis of the vegetation and ectomycorrhizae of nine ROW sites sprayed at different times in the past decade (1990; 1987; 1984), four unsprayed ROW sites (managed with

manual methods) and nine adjacent forest controls, provide data on the effectiveness of the different tree control methods and how these methods effect mycorrhizae. Vegetation data may be used as an ecological reference point for comparing mycorrhizae in different sites. Patterns of tree succession and non-target shrub recovery can also be related to mycorrhizae in this way.

An intensive study of the effects of *Tordon 101* on the mycorrhizae of spruce was also carried out at one site before and after herbicide treatment in order to elucidate the effects of this disturbance on fungal growth and the phenological patterns of the symbiosis.

A field based approach to this study was taken to provide the most ecologically relevant results, and to avoid the difficulties in extrapolating laboratory based tests on herbicides to the real environment (Wardle and Parkinson 1991; Perry et al. 1989; Greaves and Malkomes 1980; Simon-Sylvestre and Fournier 1979). This study, while examining the effects of herbicides on soil fungi, also aims to provide a vegetation database for future management of ROW's using stable plant communities and their mycorrhizas.

Mycorrhizae

The importance of mycorrhizae to ecosystems is just now being fully appreciated. Until recently, the role of fungi in the environment was thought to be primarily as saprophytic decomposers. It is now known that over 95% of all plants rely for growth and survival on fungi living within their roots.

There are three basic types of mycorrhizae found in nature: ectomycorrhizae, endomycorrhizae and ectendomycorrhizae. Ectomycorrhizae, associated with most coniferous tree species, are characterized by distinctive root modifications which are clearly visible to the naked eye (Figure 1.1). With this type of mycorrhizae, the fungal hyphae form a sheath around the root and penetrate within and between the cells to the inner root cortex. In contrast, endomycorrhizal associations, common to most herbaceous plants, are invisible to the naked eye. The fungal biomass of the endotroph, often called vesicular-arbuscular mycorrhizal fungi

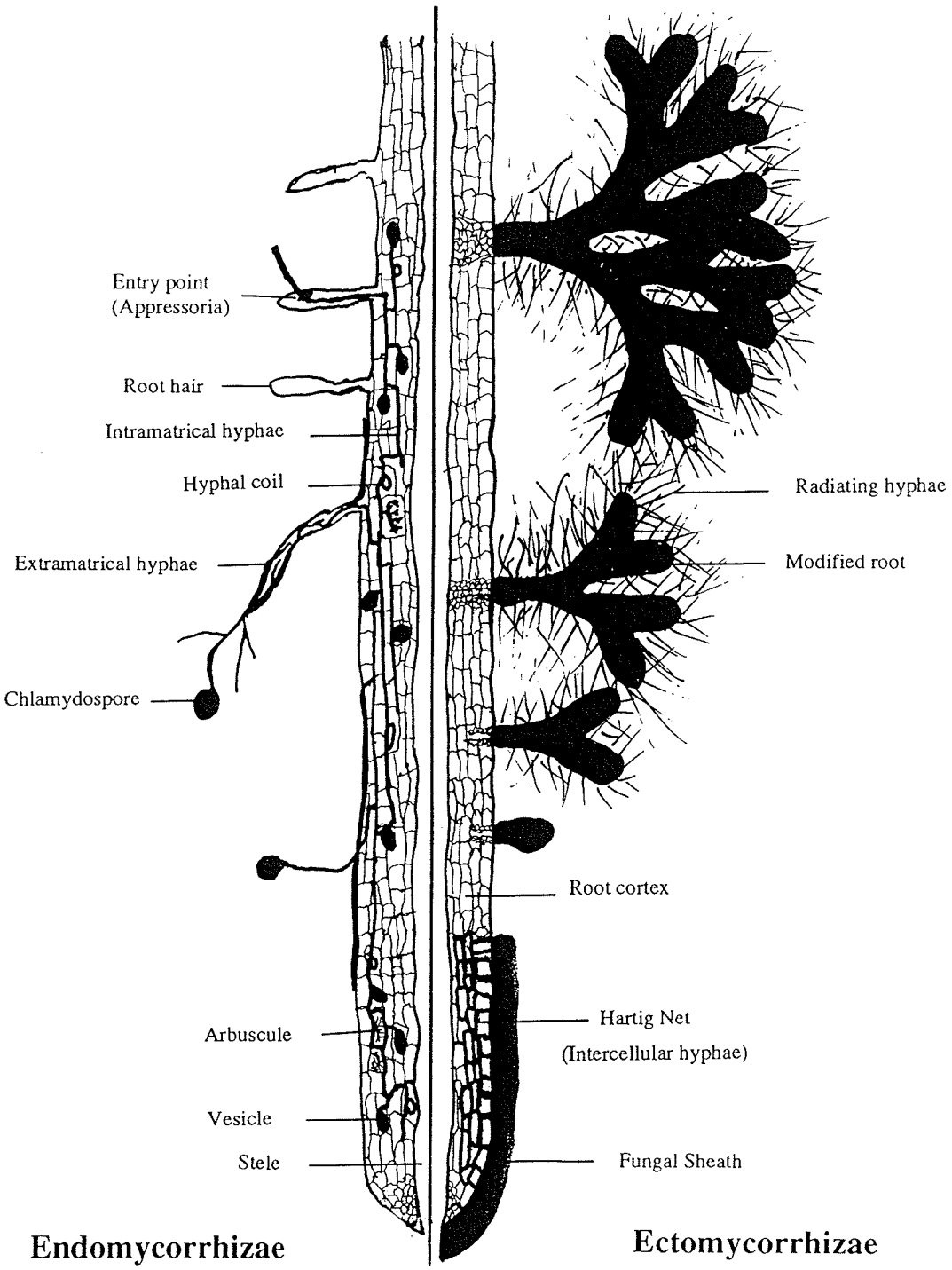


Figure 1.1. Mycorrhizal structures common to ecto- and endomycorrhizae. (Adapted from Kendrick 1985 and Harley 1969)

(VAM), is located within the root cortex and produces no overall morphological change. Ectendomycorrhizae, associated with many heathland shrubs, are intermediate to these two types and are formed by ericoid and arbutoid fungi.

To a large extent, the different types of mycorrhizae are associated with different biomes (Read 1991). Endomycorrhizas are associated with herbaceous plants growing in most areas but prefer dry soils. Most ecto- and ectendotrophic fungi rely on moisture for fruiting and so are limited by this to mesic and wet sites. Ectomycorrhizae are the best known of the three types because of their great importance in forestry. These fungi, unlike endomycorrhizal types, are easily axenically cultured and their mycorrhizae can be produced in profusion for reforestation efforts.

Ectotrophic fungi are also the most diverse of the three mycorrhizal groups. Over ten orders, 30 families, 81 genera and over 525 species of fungi are known to form ectomycorrhizae with over 280 tree species around the world (Trappe 1962). More recent studies show that at least 25 families of Basidiomycotina (common mushrooms) and seven families of Ascomycotina (fungi producing asci for reproduction) form ectomycorrhizae (Schenk 1980).

Ectomycorrhizae predominate in boreal forest areas, alpine heath and tundra zones where soils are moist, acidic and high in organic matter (Read 1991). Low temperatures over several months of the year in temperate climates slows organic matter decomposition in the soil and thus reduces nitrogen availability in these mainly closed systems. Therefore a carbon sink builds up in the soil. This carbon sink provides a niche for decomposer organisms like ectomycorrhizae which release nutrients back to the ecosystem and supply phosphorus and nitrogen to associated phytobionts.

The Mycorrhizal Symbiosis

Recent studies confirm that mycorrhizae, via enzymes secreted by the fungal symbiont (ie. phosphatases, phytases, hydrolases and proteinases), are able to access limiting elements from both the organic and inorganic components of the soil (Figure 1.2) (Cairney and

Mycorrhizal Symbiosis

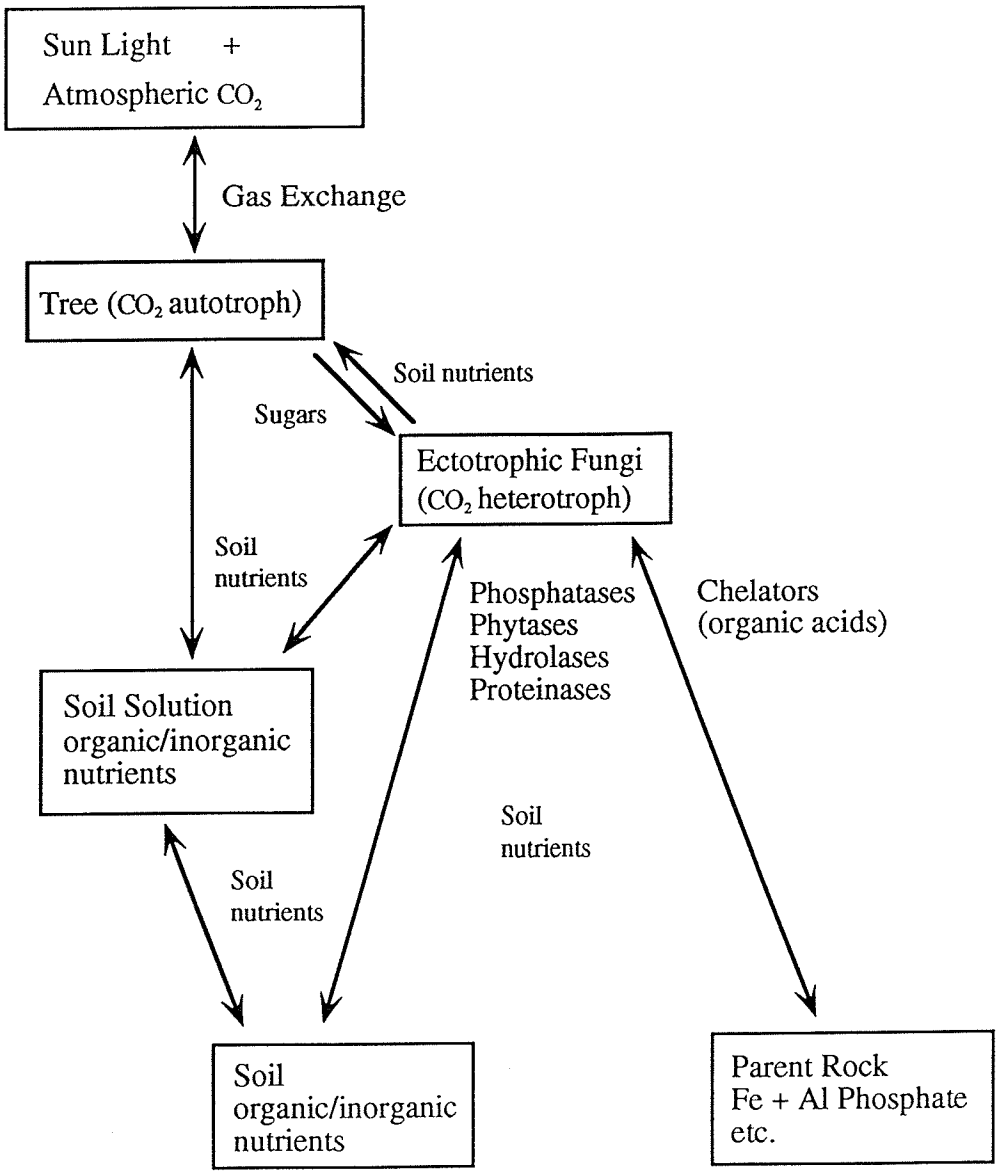


Figure 1.2. Nutrient exchange cycles between a heterotrophic mycorrhizal fungus (mycobiont) and autotrophic host plant (phytobiont).

Ashford 1991: Pankow et al. 1991a; Harvey et al. 1976). The fungal network of hyphae radiating out from the plant, increase the surface area of the root by at least one hundred times, and the length by approximately ten thousand times (Pankow et al. 1991b). Due to the increased soil volume exploited by this system, these symbiotic fungal-plant interactions are widely beneficial to the host plants and usually lead to substantial increases in growth (Perry et al. 1989; Danielson and Visser 1989; Marx et al. 1978). It has been reported that conifers in particular often cannot survive without their mycorrhizae (Perry et al. 1989; Wilde 1968).

Mycorrhizae have been shown to positively influence several aspects of plant metabolism. Hormone production, uptake of water and many trace elements including heavy metals, phosphorus and nitrogen, confer increased drought and disease resistance to phytobionts (Gogala 1991; Gange et al. 1990; Brundrett et al. 1983). In exchange for these benefits, the host plant must contribute an estimated six to 50 percent of its photosynthate to the associated mycobiont (Read 1991; Douds and Chaney 1986). Despite this sometimes large investment of photosynthate, a disruption of the mycorrhizal system generally causes a decrease in plant growth. The decline of several great forests around the world is thought to be, in part, due to losses of mycorrhizae caused by acid rain and other pollution (Heijne et al. 1992; Reich 1986).

Vegetation Related to Mycorrhizae

Vegetational components of a site can often infer presence or absence of mycorrhizal species and are important to note in a study of mycorrhizae. For example, *Piloderma croceum* (Peck) Julich, along with other Basidiomycetes such as, *Pisolithus tinctorius* (Pers.) Coker & Couch, *Thelophora terrestris* (Ehrenb.) Fr., *Amanita* spp., *Boletus* spp. and *Cortinarius* spp. and the Ascomycete *Cenococcum geophilum* Fr., form arbutoid mycorrhizae with ericaceous shrubs of the genera *Arbutus, Arctostaphylos*, *Gaultheria*, *Leucothoe* and *Vaccinium* (Schenk 1982). *Cenococcum,* in particular, is an important symbiont of *Arctostaphylos uva-ursi* (Jackson and Mason 1986). Different coniferous trees are often associated with particular

symbionts, such as *Hydenellum* spp. with pine and *Boletus* spp. with spruce (Dickinson and Lucas 1979).

Site vegetation diversity can also influence mycorrhizal diversity and the intensity of infestation (Danielson 1984). A diversity index, such as that proposed by Shannon and Weiner (1963) can thus be used to assess if site vegetation is related to mycorrhizae.

The Fungal Partner

The intensity of an ectomycorrhizal infestation on the roots of a given tree will vary according to many parameters. Factors such as the season of sampling, photoperiod, climatic conditions, soil type, pH, moisture and land use, all influence the level of mycorrhizal colonization (Coutts and Nicoll 1990a, 1990b; Fogel and Hunt 1983; Rabatin 1979; Saif and Khan 1975). In this way, the mycorrhizal attributes of a site can tell us much about its environmental status and history.

Mycorrhizae are typically found at higher levels in environments where nutrients such as nitrogen and phosphorus are limited (Menge and Grand 1978; Wallander and Nylund 1992) and are diminished in highly fertilized soils (Douds and Chaney 1986; Read 1991).

Several mycorrhizal fungi are known to have narrow pH and soil moisture ranges (Erland and Findlay 1992; Erland and Soderstrom 1991; Erland et al. 1990; Erland and Soderstrom 1990). Some predominate in mature forests while others are common in young or mid-succession stands (Read 1992; Dighton 1991; Harvey et al. 1976). Still others are known to be enhanced by fire (Dahlberg and Stenstrom 1991; Warcup 1990; Pilz and Perry 1984).

Each distinct fungal symbiont also has its own specific morphology of interaction with a given host, which may differ from host to host species. The life history strategies of the symbionts *sensu* Grime (1977) differ. Some mycorrhizae exhibit rapid 'r' type opportunist infestation patterns while others show slow but steady 'k' type infestation (Dighton 1991; Perry et al. 1989; Hepper 1988). For all mycorrhizae, there is a phenological pattern in which levels of infestation exhibit a sine-wave function according to climatic conditions (Coutts and Nicoll 1990; Harvey et al. 1978) (Figure 1.3). Note that the amplitude of the sine-wave

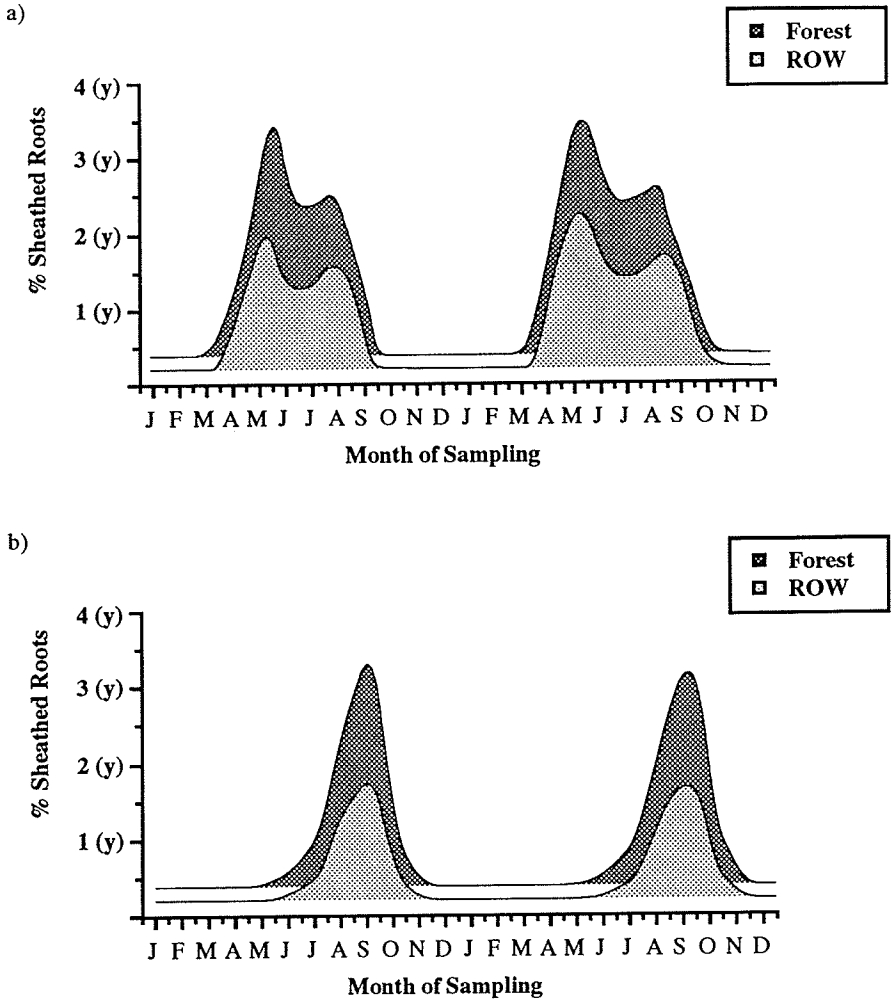


Figure 1.3. Model of phenological changes in ectomycorrhizae under a) mesic soil conditions and b) wet soil conditions. (See Harvey et al. 1976; Harvey et al. 1978; Coutts and Nicoll 1990).

depends upon site disturbance (ie. in this study herbicide application or mechanical clearing of the ROW) and soil characteristics (Dahlberg and Stenstrom 1991).

Herbicide Effects on Fungi

Many herbicides are toxic to both ecto- and endomycorrhizal fungi (Chakravarty and Chatarpaul, 1990; Chakravarty and Chatarpaul, 1988; Trappe et al., 1984; Nemec and Tucker, 1983; Trappe, 1983; Kelly and South, 1980; Marx et al., 1978). Reductions in forest productivity after herbicide treatment often occur and are attributed to the loss of mycorrhizal-forming fungi within the rhizosphere (Trappe et al. 1984).

The phenoxy herbicide *triclopyr* (3,5,6-trichloro-2-pyridyloxyacetic acid) has been shown to be toxic to the ectomycorrhizae of lodgepole pine and white spruce (Sidhu and Chakravarty 1990). At concentrations of 1ppm, inhibition of growth is observed with the ectotroph, *Suillus tomentosus* (Kauf.) Snell, Singer and Dicks and at only 10ppm, mortality occurs. Other herbicides selectively inhibit the ericoid fungi associated with heath shrubs (Litten 1985).

Generalizations about herbicide toxicity to fungi, however, cannot be made. In certain cases, trees infested by mycorrhizae are more sensitive to herbicides, while in other situations mycorrhizae seem to protect the plants from herbicide toxicity and appear to act as 'buffers' to herbicide effects (Siqueira et al. 1991). Many fungi are actually stimulated by herbicides and can use these chemicals as a nutrient source (Smith and Ferry 1979). The phenoxy herbicides 2,4-dichloro-phenoxyacetic acid (2,4-D), 2,4,5-trichlorophenoxy acetic acid (2,4,5-T) and 4-chloro-2-methylphenoxyacetic acid (MCPA) are known to stimulate mycorrhizal species including *Boletus variegatus, Boletus luteus* and *Rhizopogon roseolus* at low concentrations (10ppm) which are comparable to field application concentrations (Dasilva et al. 1977). The herbicides contain amino groups and easily digestible carbon sources (Appendix I) and enhance root exudation of the treated plants (Mullison 1985). However, at higher concentrations (100 to 250ppm) the herbicides inhibit fungal growth.

A wide range of herbicides are known to significantly affect fungal metabolism. Of the six pesticides tested in the previously mentioned study, all showed distinct and significant effects on the metabolism of the fungi. In another study of nine herbicides, six stimulated carpogenic germination of *Sclerotinia sclerotiorum*; two caused malformations in stipe development and apothecial morphology; two inhibited spore germination and one produced variable changes (Radke 1986). It is interesting to note that within B.C. Hydro ROW's, it has been observed that *glyphosate* (*N*-(phosphonomethyl) glycine) enhances the presence of saprophytic fungi (B.C. Hydro, pers. comm.).

Herbicide Properties

Picloram, the herbicide most often used for ROW management over the past decade, is known as an extremely active, highly soluble herbicide with residues that persist in treated soils for several years (Manitoba Agriculture 1991; Smith et al. 1988). Formulations used by Hydro include *Tordon 101* (a liquid formulation of picloram and 2,4-D) and *Tordon 10K* (a pellet form of picloram no longer in use due to its highly persistent nature) (Appendix I). The half life of 2,4-D and picloram are respectively four days and more than 100 days (Altom and Stritzke 1973). Because of the persistent nature of picloram it is considered several times more potent than 2,4-D. Residues of picloram above 1 to 10µg/kg have been detected in soils for 60 days after application to over 6.6 years following spraying (Watson et al. 1989).

Soil type, pH and organic matter content are critical factors in determining the leachability of the herbicide (Grover 1971). Sandy soils are least adsorbent, while peat soils have the greatest absorbency (Grover 1977). Dispersion of picloram is negligible under low soil moisture conditions, but after high levels of rainfall residues are readily leached to the 30 to 60- cm depth (Hunter and Strobbe 1972). Due to the high leachability of picloram and extensive contamination of ground and surface waters in Canada and the U.S. (Hallberg 1989; Statistics Canada 1986), picloram has been classified for restricted use by the Canadian government (Munro 1991).

Picolinic acids, such as picloram and triclopyr, are used for controlling perennial broadleaf plants and brush, and have both soil and foliar activity. The mechanism of action of these chemicals is thought to involve a disruption of protein and enzyme synthesis through effects on nucleic acid synthesis and metabolism (Ware 1989). Glass (1988) found that 20% of applied picloram was trapped within lecithin vesicles of plant cell membranes, causing a significant change in cell pH, and presumably disrupting protein activities and membrane structure and function.

At low herbicide concentrations, epinasty and leaf and stem abnormalities appear on treated plants (Mullison 1985). Physiological effects of herbicides on plants include: decreased water uptake; restricted transpiration; the production of ethylene and the exudation of carbohydrates and reducing sugars. In general, the effect of this auxin type herbicide is to promote rapid maturation and subsequent plant death (Mullison 1985).

Herbicide Effects on Target and Non-target Plants

Tordon 101, the herbicide formulation most often used by Manitoba Hydro, is used specifically for the control of conifers and deciduous trees within ROW corridors. Several of its properties, however, make its value for ROW management in boreal areas questionable. Non-target effects are not the least of these. Loss of the shrub layer inadvertently encourages target tree succession by reducing competition (Bramble and Barnes 1990). In general, this chemical formulation is highly effective at eliminating woody shrubs but often has little suppressive effect on conifers. It is interesting to note that picloram is often used by foresters to eliminate shrubs at a site in order to *promote* conifer growth (Neary et al. 1984).

In Conclusion

Although the effects of herbicides on mycorrhizal fungi within an ecosystem are not readily apparent after treatment (compared to the browned out herbs and shrubs) they are potentially relevant to ROW management. Disturbance of the soil with herbicides or

mechanical clearing may lead to shifts in mycorrhizal populations (Trappe et al. 1984; Menge and Grand 1978). These shifts can favor one plant community over another through changed competition between phytobionts as mediated by mycorrhizae and mycobionts (Gange et al. 1990; Perry et al. 1989; Hepper et al. 1988; Allan and Allan 1984). If the inoculum potential of ectomycorrhizae is high, then conifer survival will be encouraged, if the ectomycorrhizal inoculum potential is low, then shrubs may predominate (Dahlberg and Stenstrom 1991). Over the short term, reductions in tree productivity occur after herbicide treatment. However, enhanced tree growth can often ensue due to the suppression of competing plants and the slight stimulatory effect of many herbicides on mycorrhizae (Chakravarty and Chartarpaul 1990; Trappe 1983; Neary et al. 1983; Kelly and South 1980).

CHAPTER II

SITE DESCRIPTIONS AND COMPARISONS

INTRODUCTION

Management of Hydro right-of-ways (ROW's) results in significant changes in the floristic composition of ROW corridors (Magnusson 1985; MacLellan, 1982). Objectives of ROW management are to maintain low-growing, almost treeless communities beneath the lines to ensure safe and efficient service. Trees such as spruce, *Picea* spp.; jack pine, *Pinus banksiana* Michx.; tamarack, *Larix laricina* (Du Roi); aspen, *Populus tremuloides* Michx.; balsam poplar, *Populus balsamifera* L. and birch, *Betula papyrifera* Marsh., are the most prevalent tree species targeted for control in north central Manitoba.

Targeted trees in the ROW are subject to broadcast herbicide treatment (cf. *Tordon* formulations including *Tordon 101* and *Tordon 10K*) on a seven to ten year cycle. Initially, sites situated on mineral soils form grasslands, which start to develop into young secondary forest within a decade. Bog sites, having wet organic acidic soils are left with a dead *Sphagnum* moss layer. This layer serves as a substrate for *Polytrichum* spp., a moss more suited to subsequent forest development (McInnes 1989). Shrubs, broadleaf herbs and non-vascular plants, inadvertently eliminated by spraying (Magnusson 1985; McLellan 1982), are often able to out-compete target vegetation when allowed to remain at the site. In every treatment cycle, shrubs are lost along with target vegetation. These shrubs, along with herbs and non-vascular plants require approximately five to ten years to re-establish (Bramble et al. 1991; Niering and Egler 1974). This extensive loss of the natural community every decade de-stabilizes the ROW habitat and provides an open niche for unwanted target trees.

Tree growth within the ROW is suppressed using chemical treatment for the duration that the herbicides persist within the soil at effective concentrations. Herbicide retention is dependent upon soil moisture and organic content, climatic conditions and depth to ground water (Grover 1977; Hunter and Strobbe 1972). Sandy soils are least retentive, while peat soils are known to be the most retentive (Grover 1977). Movement and dissipation of picloram is negligible under low soil moisture, but under high rainfall, residues are readily leached even from peat soils (Hunter and Strobbe 1972).

Retained herbicides may not only directly affect tree growth but they may also indirectly impact on tree development and site colonization. Reductions in forest productivity after herbicide treatment can occur from the loss of ectomycorrhizal-forming fungi with their extensive mycelial fans within the rhizosphere (Trappe et al. 1984; Iyer and Wilde 1965). Many herbicides, including those in the *Picloram* chemical family, are known to be toxic to ectomycorrhizal fungi (Chakravarty and Chatarpaul, 1990; Chakravarty and Chatarpaul, 1988; Trappe et al., 1984; Trappe, 1983; Kelly and South, 1980; Marx et al., 1978). Conversely, some herbicides stimulate mycorrhizal activity and can enhance tree survival at a sprayed site (Siqueira et al. 1991; Smith and Ferry 1979). In this way, knowing the impact of a herbicide on root fungi can be critical for efficient site management (Dahlberg and Stenstrom 1991).

Recognizing the effect of herbicides in soils and the inter-connection of the above ground and below ground portions in this ecosystem, resulted in several ROW sites cleared and treated with herbicides at different times in the past to be chosen for mycological study. Studies on site flora and tree density relative to stand age (time since herbicide treatment) were aimed at determining general patterns of re-vegetation of sites by target trees and other plants so as to provide a basis for site comparisons and distinctions. These data may also add to our understanding of re-vegetation processes occurring in Manitoba ROW corridors. Ultimately the objectives in collecting the above ground plant data were to provide a data base for comparison of mycological attributes of the different sites with their vegetation and to begin to determine the nature of the linkage between ROW tree species and mycorrhizal fungi.

STUDY AREA

Location

The nine research sites (Figure 2.1) chosen for this study are located within two major physiographic regions of Manitoba. Two sites are in Manitoba's lowland area within Mixed Woods and seven are on the Precambrian Shield within the Northern Coniferous Forest zone (Weir 1983). The two lowland sites are 20km north of Mafeking, adjacent to Highway 10

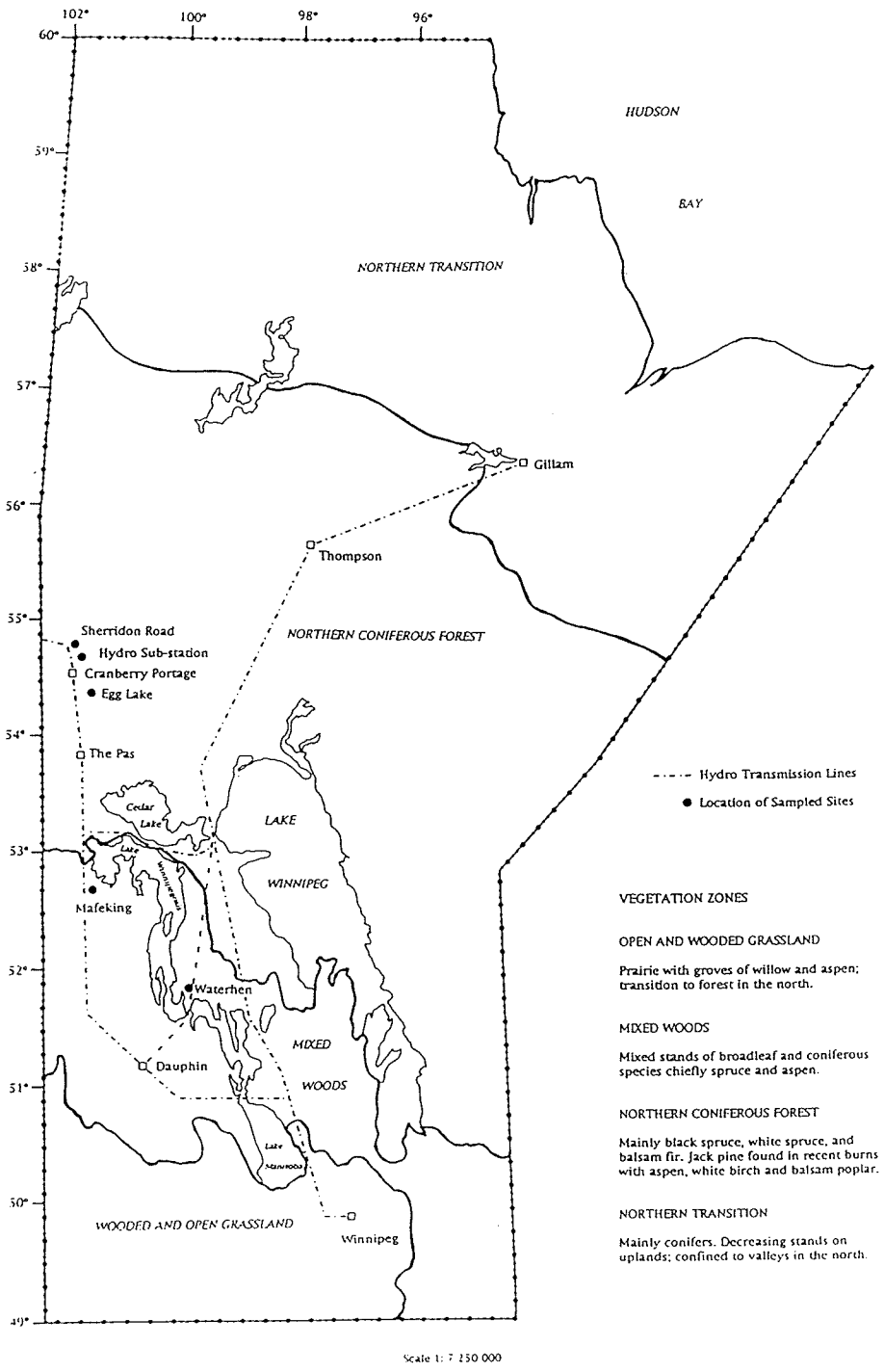


Figure 2.1: Manitoba Hydro transmission line system (in part) and location of the research sites sampled during the 1991 field season. Bold lines separate the vegetation zones of the province (as described by Weir 1983). Seven sites are along Line P58C in the Northern Coniferous Forest zone near Cranberry Portage, along Sherridon Road and near Egg Lake. Two sites are located along Line F10M in the Mixed Woods zone just north of Mafeking, and one site (see Chapter V of this thesis) is along Line G31V near the town of Waterhen.

(MS[T]R/Tower 287 and MPR/Tower 289). The seven northern sites are: three at the Cranberry Portage Hydro Sub-station 4km west of town (CS[T]U/Tower 94, CTR/Tower 96, CSR/Tower 97); two at Egg Lake 27km south of Cranberry Portage (ESU/Tower 218; and ES[P]R/Tower 222) and two off Sherridon Road 16km west of Cranberry Portage (SPU/Tower 74, and SPR/Tower 75). Of the nine research sites studied, the two lowland sites are on Line F10M and the seven northern sites are on Line P58C. Line F10M was opened in 1967 and Line P58C was originally cleared in 1974/1975. Two years after mechanical clearing, these lines were sprayed with a formulation of 2,4-D and 2,4,5-T. Subsequent herbicide treatments with *Tordon 101* were made within the last decade, except on Line F10M where *Tordon 10K* pellets were used (Appendix I).

Site names are abbreviated using a three or four letter code which indicates site location, target tree(s) sampled and position (ie. samples collected within the sprayed ROW (R), unsprayed ROW (U) or forest (F)). For example, collections of *Picea mariana* seedlings at Mafeking from the sprayed ROW are abbreviated as MSR for Mafeking Spruce ROW, while collections from the forest are indicated as MSF. The reader may wish to consult Appendix II for more information.

Geology and Topography

The Cranberry Portage sites are on Organic Cryosolic soils of fibric sphagnum. These are poorly drained peat soils with the water table 0 - 2m below ground. The parent material is granitic and the land has a hummocky surface form, with a slope of 4 - 9%. The surrounding area is granite hardrock outcrop with inclusions of basalt and calc-silicate gneiss.

The Sherridon Road site is situated on Dystic Brunisolic soils over sandy parent material. These are well to moderately well drained mineral loamy sands (non-calcareous) with the water table approximately 3m below ground. The land is morainal and hummocky with a slope of 16 - 30%. Granite hardrock outcrops are a common feature.

The Egg Lake site is on mineral parent material of morainal origin. The soil is composed of an extremely calcareous loam, with imperfect drainage. The water table is 0 - 2m below ground. The surface is hummocky with a slope of 4 - 9%. Limestone hardrock outcrops with inclusions of stony or peaty soils are a feature of this landscape.

The Mafeking sites are on limestone. The surface soil is loamy and again extremely calcareous. Drainage is imperfect, with water table 0 - 2m below ground. The surface form is slightly undulating, with a slope of 1 - 3%.

Further information on the general sites is available to the reader in Manitoba Soil Survey maps (Agriculture Canada 1992).

METHODS

Vegetation Sampling of ROW and Adjacent Forest

Sampling occurred during the summer of 1991 at six cleared ROW sites and their neighboring undisturbed forest stands. Three unsprayed sites were also sampled for a total of nine ROW study sites. Tree and tall shrub density within the ROW was determined using belt transects, each two meters wide by 23 meters long, running perpendicular to the transmission lines and across the corridor. Ten parallel transects, ten meters apart, were used at all sites, except the Mafeking spruce and tamarack site where only five transects were used. Each tree and tall shrub within the designated belt transect was recorded and measured for height. The position of each individual in relation to the ROW corridor edge was determined.

Within the ROW of each site, mean percent cover was visually estimated in each of 20 randomly located $1 m^2$ quadrats for all plants both vascular and non-vascular (cf. mosses and lichens). At the Mafeking spruce/tamarack site (MS[T]R), one quadrat was randomly located in each of the five belt transects.

Trees were sampled in the forests adjacent to the ROW sites, using 20 point-quarter points. Immature trees, with a diameter of less than 10 cm were not scored.

Vascular plants are named according to Scoggan (1978, 1979). Moss and lichen names are derived from Vitt, Marsh and Bovey (1988) and Hale (1969). Scientific names (with authorities) and the common names of all plants are listed in Appendix III.

Vegetation Sampling of Unsprayed Shrub Carrs

Cover and density of trees and tall shrubs were analyzed at two unsprayed shrub carrs located within the ROW for comparison of vegetation with mycorrhizal data from nearby sprayed ROW sites. Due to the nature of the shrub habitat, different methods were used to characterize the vegetation. Fifty $4m^2$ quadrats were analyzed at the Cranberry Portage site, and twenty $4m^2$ quadrats were studied at the Sherridon Road site. The understory vegetation at the sites was recorded but not quantified. Shrub densities were measured by counting individual shrubs (distinguished at their base) within transects delineated within the ROW.

Soil Analysis

Soil samples were taken from the ROW and neighboring forest sites in July 1991. Soil cores were extracted to a depth of 10 cm using a metal soil corer. One core was taken from each transect within the ROW sites and one from the adjacent forest. Cores were placed in eurythane bags and transported to the laboratory where they were placed in cold storage and frozen before analysis.

Soil Moisture

Soil moisture was calculated as a percentage loss of water mass from field soil when dried at 105°C for 24 hours. The calculation is as follows:

$$\frac{\text{(mass of wet soil (g) - mass of dry soil (g))}}{\text{mass of wet soil (g)}} \times 100 = \%\ \text{soil moisture}$$

Soil pH and Conductivity

Soil pH was measured in a 5:1 (5 parts distilled water to 1 part soil) suspension using a glass electrode pH meter (Fisher, Model No. 229). The conductivity of each sample was

determined from the same suspension using a Conductance/TDS meter (Analytical Instrument Science, Ser. No. COND72485) combined with a Radiometer platinum electrode.

Soil Organic Content

Soil organic content was determined by carbon combustion. Approximately 10 grams of air-dry, ground soil was taken from each soil core and placed in labeled beakers and dried at 105°C for 24 hours. A known weight of soil was placed in crucibles and placed in a muffle furnace and fired at 430°C for 18 hours. The amount of organic matter of each sample is presented as a percentage value using the following calculation:

$$\frac{\text{mass of pre-fired soil (g)} - \text{mass of fired soil (g)}}{\text{mass of pre-fired soil (g)}} \times 100 = \%\ \text{organic matter}$$

Bulk Density

Bulk density of the cores was determined by taking the dry mass of each sample and dividing by the sample volume as follows:

$$\frac{\text{mass of dry soil (g)}}{\text{volume of sample (ml)}} = \text{mass of dry soil (g)/ml}$$

Soil Water Holding Capacity

Soil water holding capacity was calculated by comparing the weight of dry soil with the weight of saturated soil. Oven dried soil of a known weight was placed in a filter paper and funnel and saturated with water. The calculation is as follows:

$$\text{g of water/g of dry soil} = \frac{\text{mass of wet soil (g)} - \text{mass of dry soil (g)}}{\text{mass of dry soil (g)}}$$

Note: g of water/g of dry soil = ml of water/g of dry soil

Climatic Data

Differences between the two major research areas (i.e. sites near Cranberry Portage compared to sites near Mafeking) in mean monthly temperature and precipitation are taken from 30 year normals (1951-1980) of The Pas and Birch River weather stations (Environment Canada, unpbl. data).

Data Analysis

Mean cover of each plant species was calculated using cover values estimated from 20 quadrats per site (except MS[T]R where only five quadrats were studied). Frequency of occurrence for each plant was also determined over the 20 quadrats and expressed as a percentage for every site. Species presence (%P) is calculated as the percent of sites in which the species is found over the total number (7) of sites studied for ground cover. A table of species and their ground cover and frequency values was then generated in decreasing order of mean cover for herbs, low and trailing shrubs, tall shrubs, target trees, bryophytes and lichens.

Density and percent composition of trees and tall shrubs was calculated for the ROW (based on transect data) and neighboring forest (based on point quarters) of each site.

Principle Components Analysis

Sites were analyzed using Principle Components Analysis (PCA) based on the vegetation. Frequency of the ROW vegetation is used to generate the first scatter diagram. Reduction of the data matrix from 90 variables to 28 by considering species having percent presence values of 29% or greater and occurring in two or more of the seven sites was carried out to minimize the distortion in data analysis and provide a more continuos distribution in the PCA results. Percent composition of the woody flora within the ROW and forest was used to generate a second scattergram.

SITE DESCRIPTIONS : VEGETATION COMPONENTS

In each of the following descriptions sites are listed by locale, line and tower number and latitude and longitude. The paragraphs begin by listing the target vegetation sampled, the year of the last herbicide treatment at the site and the site abbreviation. The percent cover of bare ground, litter and standing water are given where appropriate, followed by the total number of species observed including numbers of herbaceous, woody, bryophyte and lichen taxa. Notable species at each site are listed along with their percent cover. The percent composition of woody plants within the ROW and forest is provided. (The reader may wish to consult Tables 2.1 and 2.2 when reading the following descriptions.)

Egg Lake, Line P58C Tower 222 (Lat. 54° 24N; Long. 101° 23'E)

The spruce and jack pine 1990 ROW site (ES[P]R), near Egg Lake, Manitoba, is represented by bare ground (%C = 38) and wood litter (%C = 33) which together make up over 70% of the ground components (Figure 2.2). Recorded were 27 different species including 17 herbs, five woody plants, three bryophytes and two lichens (Table 2.1). Graminoids account for approximately 20% of ground cover of herbs at the site and include *Poa pratensis* (%C = 9), *Elymus innovatus* (%C = 7), and *Carex sartwellii* (%C = 3). *Vaccinium vitis-idaea* (%C = 1) and *Fragaria virginiana* (%C = 1) are the most abundant broadleaf herbs. Non-vascular plants include three bryophyte genera (*Polytrichum, Sphagnum and Bryum*) (%C = 2) and the lichens *Cladonia rangiferina* and *C. pyxidata.*

Picea spp. (67%), make up a large percent of the ROW woody flora, together with *Salix* spp. (16%) and *Populus tremuloides* (13%)(Table 2.2). The adjacent forest is also largely *Picea* spp. (71%) and *Populus tremuloides* (26%).

Mafeking, Line F10M Tower 287 (Lat. 52° 45'N; Long. 101° 06'E)

At the spruce and tamarack 1987 ROW site (MS[T]R), near Mafeking, Manitoba, standing water is a prevalent feature (%C = 8). Litter cover is low (%C = 1) and there is no bare ground. Unidentified graminoid species (%C = 85) predominate at the site (Figure 2.3).

Table 2.1: Percent Presence (%P), Cover (%C) and Frequency (%F) of ROW plants recorded in north central Manitoba. (The plants are listed in decreasing order of mean cover.) (P = Present; ND = Not Determined)

Species/Cover		C. Portage CSR* (1984)		C. Portage CTR (1984)		Sherridon SPR (1984)		Mafeking MSTR (1987)		Mafeking MPR (1987)		Egg Lake ESPR (1990)		Egg Lake ESU (1976)	
	%P	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F
HERBS															
Graminoid spp. (unknown)	86			17	85	6	65	85	100	17	95	5	20	<1	5
Elymus innovatus	29										P	7	40		
Carex spp.	57			9	75	5	60	1	20					2	55
Fragaria virginiana	100	<1	5	2	15	1	5	<1	40	3	85	1	5	4	15
Maianthemum canadense	71	1	10			8	85			<1	5	<1	5	1	70
Poa pratensis	14											9	20		
Equisetum spp.	71	1	50	1	65			1	40			<1	10	2	95
Carex cf. aenea	43	4	45									<1	5		
Carex sartwellii	14											3	20		
Galium boreale	43			<1	5			2	20	1	55				
Unknown Herbs	86			1	5	<1	10	<1	20	1	20	<1	5	<1	5
Caltha palustris	29			2	30									<1	5
Apocynum androsaemifolium	29					2	10			<1	10				
Antennaria howellii	14									2	20				
Poa spp.	14											1	5		
Petasites sagittatus	43	<1	15	1	50							<1	5		
Vicia americana	14									1	50				
Taraxacum officinale	43					<1	5			1	5	<1	5		
Arctium minus	14									1	15				
Juncus spp.	14			<1	15										
Oryzopsis pungens	14											<1	10		
Epilobium angustifolium	71	<1	5	<1	5					<1	10	<1	5	<1	5
Rubus chamaemorus	29			<1	10									<1	30
Aster ciliolatus	14									<1	50				
Cornus canadensis	29	1	15	<1	5										
Habenaria spp.	14			<1	35										
Petasites palmatus	14			<1	30										
Ranunculus spp.	29			<1	5								P		
Saxifrage tricuspidata	14					<1	20								
Polygonum aviculare	14			<1	15										
Cerastium arvense	14			<1	15										
Anemone patens	14					<1	15								
Empetrum nigrum	14													<1	15
Lathyrus ochroleucus	14									<1	10				
Anemone multifida	14									<1	10				
Mentha arvensis	14			<1	5										
Lilium spp.	14									<1	5				
Comandra umbellata	14									<1	5				
Geranium bicknellii	14											<1	5		
Euphorbia esula	14									<1	5				
Viola cucullata	14									<1	5				
Violet spp.	14					<1	5								

Table 2.1 Con't.

Species/Cover		C. Portage CSR (1984)		C. Portage CTR (1984)		Sherridon SPR (1984)		Mafeking MSTR (1987)		Mafeking MPR (1987)		Egg Lake ESPR (1990)		Egg Lake ESU (1976)	
	%P	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F
HERBS Con't.															
Zizia aptera	14									<1	5				
Steironema ciliatum	14									<1	5				
Pedicularis lanceolata	14											<1	5		
Campanula rotundifolia	14									<1	5				
Solidago canadense	14									<1	5				
Aster spp.	14													<1	5
Orchis rotundifolia	14														P
LOW/TRAILING SHRUBS															
Ledum groenlandicum	57	9	60	6	40			<1	20					20	95
Chamaedaphne calyculata	14													21	95
Arctostaphylos uva-ursi	71	4	15	<1	5	5	30			9	55			<1	10
Vaccinium vitis-idaea	71			1	15	<1	25			5	15	1	5	2	45
Vaccinium angustifolium	43	3	35	1	5	2	15								
Oxycoccus microcarpus	29			<1	5									2	70
Kalmia polifolia	29	1	15											1	55
Juniperus horizontalis	14									2	20				
Andromeda polifolia	14													1	30
Rosa spp.	43					<1	10	<1	20	<1	5			<1	5
Linnaea borealis	43			<1	10	<1	5			<1	5				
Potentilla fruticosa	29					<1	5			<1	5				
Shepherdia canadensis	14									<1	5				
TALL SHRUBS															
Salix spp.	100	4	10	4	35	<1	5		P	<1	5		P	1	20
Alnus rugosa	29				P	3	5								
Lonicera caerulea	14					1	40								
Rubus idaeus	14					1	15								
Betula glandulosa	43	<1	5	<1	5									<1	5
Cornus stolonifera	14						P								
TARGET TREES															
Picea spp.	100	<1	20	5	30		P		P		P	1	20	4	30
Larix laricina	71		P	2	10				P	<1	5			2	10
Pinus banksiana	57		P				P			4	20		P		
Populus tremuloides	100		P		P	<1	5		P	1	35	1	5		P
Betula papyrifera	71	<1	5	2	10		P				P				P
Populus balsamifera	43				P		P				P				

Table 2.1 Con't.

Species/Cover		C. Portage CSR (1984)		C. Portage CTR (1984)		Sherridon SPR (1984)		Mafeking MSTR (1987)		Mafeking MPR (1987)		Egg Lake ESPR (1990)		Egg Lake ESU (1976)	
	%P	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F	%C	%F
NON-VASCULAR PLANTS															
Mosses (Total)	100	24	80	46	85	8	50	2	40	<1	5	2	40	31	90
Sphagnum spp.	86	8	25	21	50			2	40	<1	5	<1	10	28	75
Polytrichum spp.	71	10	45	<1	10	8	50					1	40	3	40
Fissidens spp.	29	3	20	17	40										
Rhacomitrium spp.	29	2	30	7	15										
Bryum spp.	43	1	20									<1	25	<1	7
Mnium spp.	14			<1	10										
ALGAE															
Spirogyra spp.	14	1	20												
LICHENS															
Lichens (Total)	86	10	40	5	10	24	95			1	35	<1	30	9	55
Cladonia spp. (Total)	86	10	40	4	5	24	95			1	35	<1	30	9	55
Cladonia rangiferina	86		40		5		95				25		15		53
Cladonia pyxidata	71		40		5		80				25		15		
Cladonia bellidiflora	14						67								
Cladonia sp.	43		20				27				20				
Cetraria spp.	43		20				27								20
Cladonia chlorophaea	29		10				53								
Cladonia gracilis	43		10				40								7
Peltigera canina	29		10	1	5										
GROUND COVER															
Litter (Total)	100	13	50	34	75	11	95	1	20	40	70	38	85	10	50
Bare ground (Total)	100	4	25	1	10	26	95			10	30	33	80	7	50
Water	43	5	20	4	30			8	20						

* Site codes are: C: Cranberry Portage; S: Sherridon Road; M: Mafeking; E: Egg Lake; Tree species: S: Spruce; T: Tamarack; P: Pine; Collection site: R: Sprayed ROW; U: Unsprayed ROW; F: Forest. Complete scientific names and authorities to all plant species are given in Appendix III.

Table 2.2a and b: Percent composition of woody vegetation within the ROW, unsprayed ROW and forest of each research site.

a) Spruce Dominated Research Sites

Site Name (Year sprayed)	Egg Lake (1976)		Cranberry Portage (1984)		Mafeking (1987)		Egg Lake (1990)	
Site abbreviation	ESU[1]	ESF	CSR	CSF	MS[T]R	MS[T]F	ES[P]R	ES[P]F
Picea mariana	63.1	96.7	43.1	78.3	44.4	90.0	67.1	71.3
Larix laricina	17.0	1.7	0.4	1.7	2.8	10.0	-	-
Pinus banksiana	-	-	0.4	1.7	-	-	4.3	1.3
Populus balsamifera	-	-	-	-	-	-	-	1.3
Populus tremuloides	2.6	-	2.9	-	2.8	-	12.9	26.3
Betula papyrifera	0.6	-	15.9	-	-	-	-	-
Salix spp.	16.7	1.7	34.7	-	50.0	-	15.7	-
*Alnus rugosa**	-	-	2.5	18.3	-	-	-	-

b) Pine, Tamarack and Poplar Dominated Research Sites and Shrub Carrs

Site Name (Year sprayed)	Mafeking (1987)		Sherridon Road (1984)		Cranberry Portage (1984)		Shrub Carrs[2] (1976)	
Site abbreviation	MPR	MPF	SPR	SPF	CTR	CTF	CS[T]U	SPU
Picea mariana	2.4	5.0	2.4	6.25	20.2	91.0	1.0	5.0
Larix laricina	1.0	-	-	-	18.6	2.0	1.0	-
Pinus banksiana	2.8	50.0	53.2	87.5	-	1.0	-	3.0
Populus balsamifera	2.4	-	8.9	-	2.6	2.0	1.0	-
Populus tremuloides	71.2	45.0	17.8	5.0	0.3	-	-	9.0
Betula papyrifera	1.2	-	3.6	-	3.9	2.0	-	2.0
Salix spp.	19.0	-	1.1	-	53.6	1.0	4.0	21.0
Alnus rugosa	-	-	13.0	1.2	0.8	1.0	54.0	60.0

[1] Site codes are: C=Cranberry Portage; S=Sherridon Road; M=Mafeking; E=Egg Lake; Tree species: S=Spruce; T=Tamarack; P=Pine; Collection site: R=Sprayed ROW; U=Unsprayed ROW; F=Forest. [2] Percent cover estimates (not percent composition) and are based on fifty $4m^2$ quadrats for CS[T]U and twenty $4m^2$ quadrats for SPU. **Alnus rugosa* (Du Roi) Spreng. var. *americana* (Regel) Fern.: syn. *Alnus incana*

Figure 2.2:
Egg Lake Spruce and Pine ROW site (ES[P]R Tower 222). Line P58C. Bare ground, debris and standing dead jack pine and poplar characterize the site. Tree seedlings remaining within the ROW are generally yellowed with chlorotic tissue and show signs of apical elongation and epinasty. This ROW was sprayed by Hydro in 1990 with *Tordon 101*. In late 1990, MTS cut and mulched half of the corridor while installing a fiber optics cable, leaving it highly disturbed (June 1991).

Figure 2.3:
Mafeking Spruce and Tamarack ROW site (MS[T]R Tower 286). Line F10M. Grasses dominate the site with common occurrence of spruce and tamarack seedlings throughout the corridor. This ROW was sprayed in 1987 with *Tordon 10K* (June 1991).

2.2

2.3

There are a total of 13 species identified at the site including six herbs, two low shrubs, one tall shrub, three target trees and one bryophyte. Broadleaf herbaceous species include *Galium boreale* (%C = 2), *Fragaria virginiana* (%C = 1), *Carex* spp. (%C = 1), and *Equisetum* spp. (%C = 1). Low shrubs include *Rosa* spp. (%C < 1) and *Ledum groenlandicum* (%C < 1). Bryophytes are most notably represented by the *Sphagnum* genus (%C = 2).

Woody flora of the ROW is high in percent of *Picea* spp. (44%) and *Salix* spp. (50%). The adjacent forest is largely *Picea* spp. (90%) together with *Larix laricina* (10%).

Cranberry Portage, Line P58C Tower 97 (Lat. 54° 35'N; Long. 101° 23'E)

At the spruce 1984 ROW site (CSR), located at the Cranberry Portage Hydro Sub-station, litter (%C = 13) and bare ground (%C = 4) are common. Recorded were 31 plant species including seven herbs, four low shrubs, two tall shrubs, five target trees, five bryophytes, seven lichens and one bluegreen alga. Unidentified graminoid species (%C = 33) are prevalent at the site together with mosses (%C = 24) and lichens (%C = 10)(Figure 2.4). Bryophyte genera include *Polytrichum* (%C = 10), *Sphagnum* (%C = 8), *Fissidens* (%C = 3), *Rhacomitrium* (%C = 2) and *Bryum* (%C = 1). Lichens include *Cladonia rangiferina, C. pyxidata, Cetraria* spp. and *Peltigera canina.* The low shrub *Ledum groenlandicum* (%C = 9) is the most abundant ericoid shrub, together with *Vaccinium angustifolium* (%C = 3) and *Arctostaphylos uva-ursi* (%C = 4). *Carex cf. aenea* (%C = 4), together with *Maianthemum canadense, Steironema ciliatum, Petasites sagittatus* and *Senecio* sp., indicate the wetness of the site.

ROW woody plants include *Picea spp.* (43%), *Salix* spp. (35%) and *Betula papyrifera* (16%). The adjacent forest is largely *Picea spp.* (78%) along with *Alnus rugosa* (18%).

Egg Lake, Line P58C Tower 218 (Lat. 54° 24N; Long. 101° 23'E)

At the unsprayed spruce ROW site (ESU), located near Egg Lake, Manitoba (Figures 2.5 and 2.6), litter (%C = 10) and bare ground (%C = 7) are common. The total number of species is 32 including 12 herbs, eight low shrubs, two tall shrubs, four target trees, three

Figure 2.4:
Cranberry Portage Spruce ROW site (CSR Tower 97). Line P58C. Labrador tea, shown in white flower, together with grasses and mosses dominate the site vegetation. Black spruce, paper birch and willow are the most common tall woody species. The site was last sprayed in 1984 with *Tordon 101* (June 1991).

Figure 2.5:
Egg Lake Spruce ROW site (ESU Tower 218). Line P58C. Shown in general aspect, a dense stand of bog birch, *Betula glandulosa* precedes the collection site seen in the background as a high density of mature spruce and tamarack. The last herbicide application at the site occurred after line clearance in 1976 with a formulation of 2,4-D and 2,4,5-T (June 1991).


2.4


2.5

Figure 2.6:
Egg Lake Spruce ROW site (ESU Tower 218). Line P58C. Site vegetation is dominated by *Carex* spp., *Sphagnum* moss and the ericacious shrubs, leatherleaf and labrador tea. Black spruce, tamarack and willow are the most common woody species. The transect, delineated by cord with pink markers shown at one meter intervals, is 2m wide by 12m across the ROW (June 1991).


2.6

bryophytes and three lichens. The ericaceous shrubs *Chamaedaphne calyculata* (%C = 21) and *Ledum groenlandicum* (%C = 20) are notable at the site. Other low shrubs and trailing plants include *Oxycoccus microcarpus* (%C = 2), *Kalmia polifolia* (%C = 1), *Vaccinium vitis-idaea* (%C = 2), *Andromeda polifolia* (%C < 1), and *Arctostaphylos uva-ursi* (%C < 1). *Equisetum* spp. (%C = 2) and *Maianthemum canadense* (%C = 1) are the most abundant broadleaf herbs together with *Rubus chamaemorus* (%C < 1) and *Fragaria virginiana* (%C = 4). Bryophyte genera include *Sphagnum* (%C = 28), *Polytrichum* (%C = 3) and *Bryum* (%C < 1). Lichens include *Cladonia rangiferina* (%C = 9), *C. gracilis* (%C < 1) and *Cetraria* spp. (%C < 1).

Woody flora of the ROW is largely *Picea* spp. (63%) together with *Larix laricina* (17%), *Salix* spp. (17%) and *Populus tremuloides* (3%). The adjacent forest is virtually all *Picea* spp. (97%) with minor components of *Larix laricina* (1.5%) and *Salix* spp. (1.5%).

Mafeking, Line F10M Tower 286 (Lat. 52° 45'N; Long. 101° 06'E)

At the jack pine 1987 ROW site (MPR), near Mafeking, Manitoba, litter (%C = 40) and bare ground (%C = 10) are prevalent ground components (Figure 2.7). The total number of species is 41, including 23 herbs, seven low shrubs, one tall shrub, six target trees, one bryophyte and three lichens. Unidentified graminoid species (%C = 17) and the trailing shrub *Arctostaphylos uva-ursi* (%C = 9) are common site flora. Broadleaf herbs include *Fragaria virginiana* (%C = 3), *Galium boreale*(%C = 1), *Vicia americana* (%C = 1) and *Aster ciliolatus* (%C < 1). Low ground cover includes*Vaccinium vitis-idaea* (%C = 5) and *Antennaria howellii* (%C = 2). *Juniperus horizontalis* (%C = 2) is a notable floristic component.

Woody flora of the ROW includes *Populus tremuloides* (71%), *Salix* spp. (19%) and *Pinus banksiana* (3%). The adjacent forest is largely *Pinus banksiana* (50%) together with *Populus tremuloides* (45%).

Sherridon Road, Line P58C Tower 74 (Lat. 54° 35N; Long. 101° 23'E)

At the jack pine 1984 ROW site (SPR), located at Sherridon Road, just west of Cranberry Portage, bare ground (%C = 26) and litter (%C = 11) are prevalent (Figure 2.8).

Figure 2.7:
Mafeking Jack pine ROW site (MPR Tower 286). Line F10M. Grasses are dominant with litter, bare ground and bearberry representing significant cover. Poplar, willow and jack pine are the most common woody species. The site was last sprayed in 1987 with *Tordon 10K* (June 1991).

Figure 2.8:
Sherridon Road Jack pine ROW site (SPR Tower 74). Line P58C. A high cover of bare ground and lichens characterize this site. Flora in the foreground is dominated by Wild-lily-of-the-valley, grasses and hairy cap*Polytrichum* moss. A shrub thicket (road buffer-zone) seen in the distance is dense with jack pine, black spruce and alder. The site was sprayed in 1984 with *Tordon 101* (June 1991).

2.7

2.8

total number of species is 34 including 10 herbs, six low shrubs, five tall shrubs, five target trees, one bryophyte and seven lichens. *Cladonia* spp. (%C = 24) and *Maianthemum canadense* (%C = 8) are the most abundant plants at the site. Unidentified graminoids (%C = 6), *Carex* spp. (%C = 4) and the trailing shrub, *Arctostaphylous uva-ursi* (%C= 5) are common at the site. *Polytrichum* (%C = 8) is the only bryophyte present.

Tree flora of the ROW is largely composed of *Pinus banksiana* (53%) together with *Populus tremuloides* (18%) and *Populus balsamifera* (9%). ROW shrub flora includes *Alnus rugosa* (13%), *Salix* spp. (1%), *Lonicera caerulea* (<1%) and *Rubus idaeus* (<1%). The adjacent forest is largely *Pinus banksiana* (88%) with a small component of *Picea* spp. (6%) and *Alnus rugosa* (1%).

Cranberry Portage P58C Tower 96 (Lat. 54° 35'N; Long. 101° 23'E)

At the tamarack 1984 ROW site (CTR), located at the Cranberry Portage Hydro Sub-station, litter (%C = 34) is prevalent and there is over 4% standing water (Figure 2.9). The total number of species is 40 including 18 herbs, six low shrubs, three tall shrubs, five target trees, five bryophytes and three lichens. Mosses include *Sphagnum* spp. (%C = 21), *Fissidens* spp. (%C = 17) and *Rhacomitrium* spp. (%C = 7). Unidentified graminoids (%C = 17), *Carex* spp. (%C = 9) and the ericaceous shrub *Ledum groenlandicum* (%C = 6) are the most notable plants. *Equisetum* spp., *Petasites sagittatus*, *Juncus* spp., *Habenaria* spp., *Polygonum aviculare*, *Caltha palustris* and *Petasites palmatus* characterize the marshy nature of the site. Lichens include *Cladonia rangiferina, C. pyxidata* and *Peltigera canina.*

Salix spp. (54%), *Picea* spp. (20%) and *Larix laricina* (19%) are the major components of the woody flora of the ROW. The adjacent forest is 91% *Picea* spp. together with *Larix laricina* (2%), *Populus balsamifera* (2%) and *Betula papyrifera* (2%).

Cranberry Portage, Line P58C Tower 94 (Lat. 54° 35'N; Long. 101° 23'E)

At the spruce and tamarack unsprayed ROW site (CS[T]U) near Cranberry Portage, Manitoba (Figure 2.10), open water is a notable feature of the site. (Ground cover estimates

Figure 2.9:
Cranberry Portage Tamarack ROW site (CTR Tower 96). Line P58C. Labrador tea, shown in white flower, together with grasses and sedges, dominate the site flora. Tall woody species include willow, tamarack and black spruce. The site was last sprayed in 1984 with *Tordon 101* (June 1991).

Figure 2.10:
Line P58C near Tower 94. The shrub thicket seen in the distance, sampled as the Cranberry Portage Spruce and Tamarack Unsprayed ROW site (CS[T]U), is dominated by alder together with willow and redosier dogwood. The site was last sprayed in 1976 with *2,4-D* and *2,4,5-T* (June 1991).

2.9

2.10

were not made.) Herbaceous plants include *Carex* spp., *Equisetum* spp., *Fragaria virginiana*, *Maianthemum canadense*, *Cornus canadensis*, *Galium triflorum* Michx., *Campanula aparinoides* Pursh, *Epilobium angustifolium*, *Rosa* spp. and *Polytrichum* moss.

The site flora is largely composed of tall shrubs including *Alnus rugosa* (C = 54%), *Salix* spp. (C = 4%) and *Cornus stolonifera* (C = 1%). *Picea* spp., *Larix laricina* and *Populus balsamifera* collectively represent less than 5% cover.

Sherridon Road, Line P58C Tower 74 (Lat. 54° 35N; Long. 101° 23'E)

The jack pine unsprayed site (SPU) near Sherridon Road, Manitoba, is similar to the adjacent sprayed ROW with its predominance of sandy bare ground. (Ground cover estimates were not made.) Broadleaf herbs present include *Maianthemum canadense*, *Arctostaphylos uva-ursi*, *Vaccinium vitis-idaea*, *Rubus idaeus*, *Vaccinium angustifolium* and *Apocynum androsaemifolium.* Lichens are primarily of the genus *Cladonia.*

The site is dense in cover of two shrubs, *Alnus rugosa* (C = 60%) and *Salix* spp. (C = 21%) (Figure 2.11). Target trees, such as *Pinus banksiana* (C = 3%), *Picea* spp.(C = 5%), *Populus tremuloides* (C = 9%) and *Betula papyrifera* (C = 2%) are present at low densities.

SITE DESCRIPTIONS : SOIL CHARACTERISTICS

Soil characterists of the sites are presented in Table 2.3. (Soil samples were taken at all sites, however, collections from the Cranberry Portage spruce sites, Mafeking pine forest and Egg Lake forest sites were accidentily discarded.) In the following descriptions "high" and "low" represent values well above (high) or below (low) mean values of each soil factor over all sites and collections.

Samples taken from the Cranberry Portage tamarack (CTR) site reflect a fen type of habitat: high percent water (64%); high organic content (47%); high conductivity (324µS) and ~ mean pH (6.3). Unsprayed site data is much the same with: high percent water (68%); high organic content (43%); high conductivity (450µS) and intermediate pH (7.1). Both sites

Figure 2.11:
Sherridon Road Pine Unsprayed ROW site (SPU Tower 94). Line P58C. This dense shrub thicket is dominated by alder together with willow. The site was last sprayed in 1976 with *2,4-D* and *2,4,5-T* (June 1991).


2.11

Table 2.3: Soil characteristics of research sites including percent water, pH, conductivity, percent organic matter, density, ml H_2O/g soil and ml H_2O/ml soil. Means and standard deviations are based on five soil samples, except at SPR where seven samples were taken.

Site Name Site Code Soil Property	C. Portage CTR x ± SD	C. Portage CS[T]U x ± SD	Sherridon SPR x ± SD	Sherridon SPF x ± SD	Sherridon SPU x ± SD	Mafeking MS[T]R x ± SD	Mafeking MS[T]F x ± SD	Mafeking MPR x ± SD	Egg Lake ES[P]R x ± SD
% Water	64 ± 25	68 ± 6.3	7.6 ± 1.8	8 ± 2	38 ± 11	85 ± 5.3	78 ± 4.5	29 ± 6.4	52 ± 19
pH	6.3 ± 0.6	7.1 ± 0.2	5.4 ± 0.4	6 ± 0.7	4.9 ± 0.3	6.4 ± 0.8	5.2 ± 0.5	6.6 ± 0.3	4.9 ± 0.5
Conductivity (µS)	324 ± 94	450 ± 85	68 ± 14	102 ± 25	231 ± 98	363 ± 52	338 ± 59	167 ± 35	487 ± 290
% Organic matter	47 ± 37	43 ± 15	4.3 ± 2.7	3.7 ± 1.9	21 ± 12	77 ± 6.4	86 ± 4.1	11 ± 4.1	53 ± 30
Density (g/ml)	0.5 ± 0.3	0.5 ± 0.1	1.1 ± 0.2	1.2 ± 0.1	0.7 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	0.9 ± 0.1	0.5 ± 0.3
ml H_2O/g soil	3.2 ± 2.2	2.7 ± 1.2	0.6 ± 0.1	0.5 ± 0.1	1.4 ± 0.6	7.5 ± 2.5	6.5 ± 1.6	0.8 ± 0.3	3.3 ± 1.8
ml H_2O/ml soil	1.1 ± 0.1	1.2 ± 0.2	0.6 ± 0.1	0.6 ± 0.1	0.8 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	0.7 ± 0.2	1.1 ± 0.2

*Site codes are: E=Egg Lake; C=Cranberry Portage; M=Mafeking; S=Sherridon Road; Tree species: S=Spruce; T=Tamarack; P=Pine; Collection sites: R=Sprayed ROW; F=Forest; U=Unsprayed ROW.

have relatively high water holding capacity (3.2 and 2.7 ml H_2O/g soil, respectively).

Soil samples taken from the Sherridon Road Pine ROW and forest reflect the sandy nature of the site: low percent water (7.6 and 8.0%, respectively); low organic content (4.3 and 3.7%, respectively); low conductivity (68 and 102μS, respectively) and high density (1.1 and 1.2g/ml, respectively). The ROW is slightly more acidic than the forest (pH 5.4 and 6.0 respectively). Water holding capacity is low in both the ROW and forest (0.6 and 0.5 ml H_2O/g soil, respectively). The unsprayed site data has markedly different attributes: higher percent water (38%); ~ mean organic content (21%); ~ mean conductivity (231μS); ~ mean density (0.7g/ml) and low pH (4.9). The water holding capacity at 1.4 ml H_2O/g soil is twice that of the ROW or forest.

Soil samples taken from the Mafeking Spruce and Tamarack ROW and forest are similar in attributes: high percent water (85 and 78%, respectively); high organic content (77% and 86%, respectively); high conductivity (363 and 338μS, respectively) and low density (0.2 g/ml at both). The pH is more alkaline within the ROW than the forest (6.4 versus 5.2), while the water holding capacities are both very high (7.5 and 6.5 ml H_2O/g soil, respectively).

Soils at the Mafeking Pine site (MPR) are: ~ mean percent water (29%); low organic content (11%); low conductivity (167μS); ~ mean pH (6.6) and high bulk density (0.9g/ml). Water holding capacity is low at 0.8 g H_2O/g soil.

Soil samples taken from the Egg Lake spruce and pine ROW (ES[P]R) are high in percent water (52%). Organic content (53%) and conductivity (487μS) are also high. The soil is acidic (pH = 4.9) and has a relatively high water holding capacity (3.3 ml H_2O/g). Bulk density is near mean levels (0.5g/ml).

SITE DESCRIPTIONS : TEMPERATURE AND MOISTURE

Weather data for reporting stations near the research locations show slight differences in mean monthly temperatures (Figure 2.12) and annual precipitation (Figure 2.13). (Sherridon Road, Cranberry Portage and Egg Lake sites are represented by data from The Pas

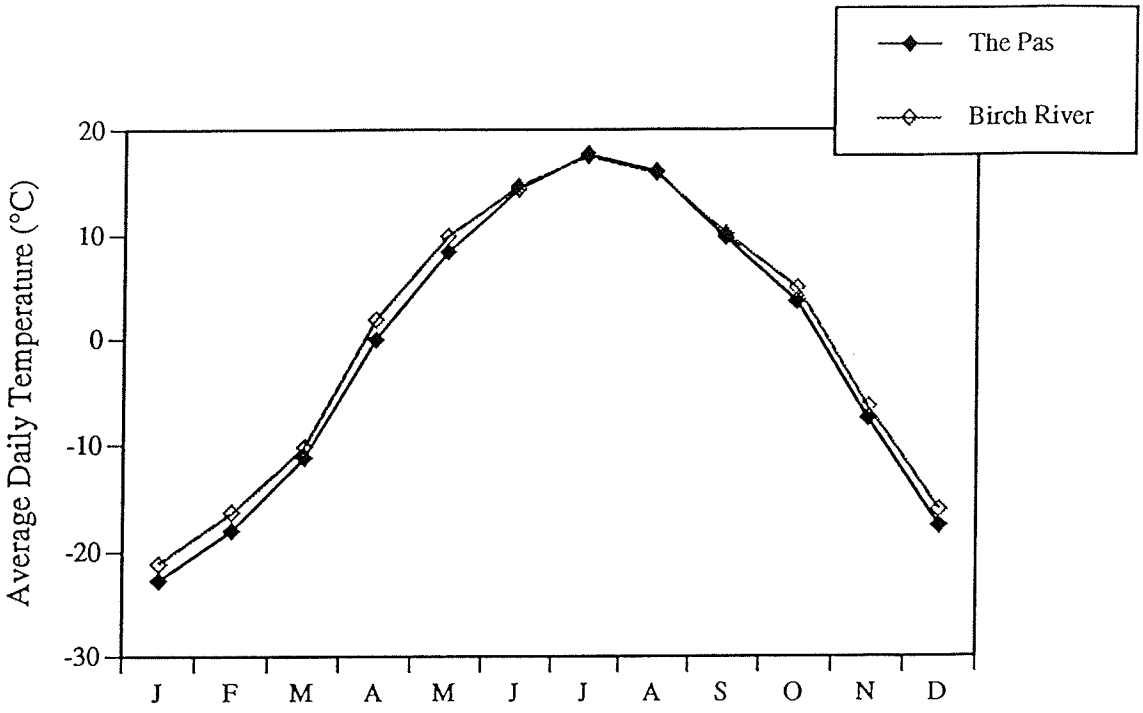


Figure 2.12: Mean monthly temperatures for The Pas and Birch River reporting stations. Means are based on thirty year normals of average daily temperatures taken in degrees Celsius.

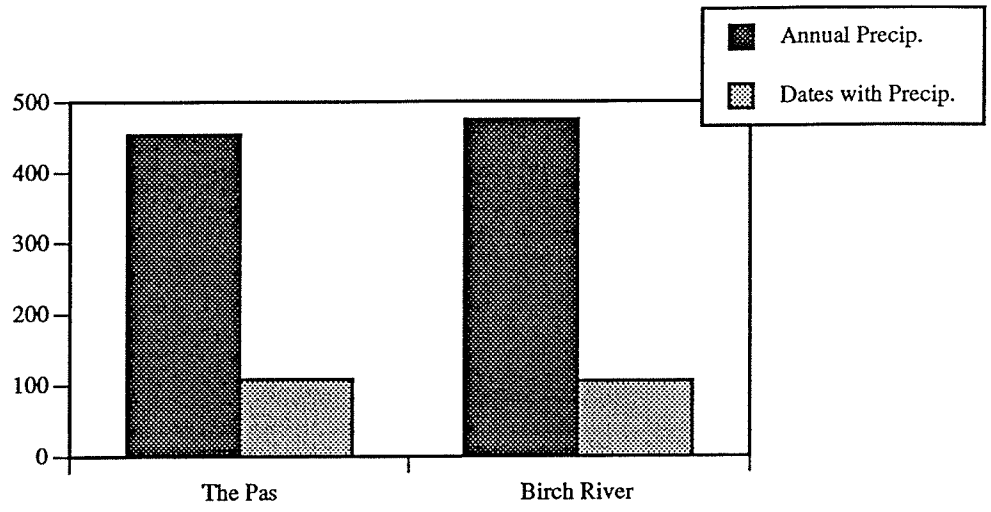


Figure 2.13: Annual precipitation and days with precipitation based on thirty year normals (1951-1980) for reporting stations near the major research sites.

and Mafeking sites are represented by Birch River data.) The Mafeking sites are two to three degrees warmer over several months of the year, although growing-season temperatures are virtually the same. Annual precipitation is slightly higher near Mafeking while number of dates with rainfall are the same for the two reporting stations.

SITE COMPARISONS : WOODY PLANT COMPOSITION AND DENSITY

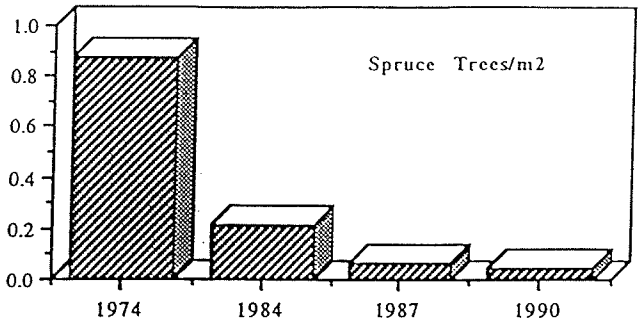
Composition of Woody Vegetation

Within the ROW and neighboring forest collection areas, the ESU, CSR, MS[T]R and ES[P]R sites are high in percent composition of *Picea mariana* (together with *Picea glauca* at ESU), ranging between 43 to 85% within the ROW and 71 to 97% within the adjacent forest (Table 2.2). The MPR and SPR sites are both high in percent composition of *Pinus banksiana* within the forest (at 50 and 88%, respectively) but only the SPR site at 53% is high in *P. banksiana* within the ROW. *Populus tremuloides* predominates at the MPR site at 71%. *Larix laricina* is prevalent at the CTR site (18.6%) and the ESU site (17%) and is a minor component at the MS[T]R site at 2.8%. *Betula papyrifera* is present at several of the sites, and comprises over 15% of the woody vegetation at the CSR site. *Salix* spp. are common at Cranberry Portage, Mafeking and Egglake, and comprise over 50% of the tall woody species at the MS[T]R and CTR sites. *Alnus rugosa* dominates the cover at both CS[T]U and SPU sites but remains only a minor component of the 1984 sprayed ROW sites.

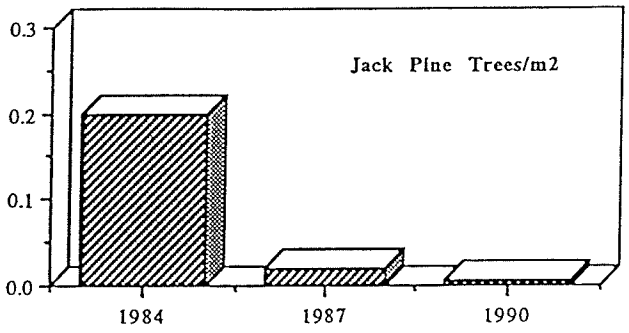
ROW, Unsprayed ROW and Forest Tree Densities

Within ROW sites, 'sampled' target tree density (ie. the density of trees sampled for mycorrhizae) is inversely proportional to time since spraying (Figure 2.14). The ES[P]R site, treated with *Tordon 101* in 1990, has a density of 500 spruce trees/ha. The MS[T]R site, treated with *Tordon 10K* in 1987, has a density of 700 spruce trees/ha. The CSR site, treated with *Tordon 101* in 1984, has 2200 spruce trees/ha and at the ESU site, treated with *2,4-D* and *2,4,5-T* in 1976, spruce density is 8800 spruce trees/ha.

a) Spruce Research Sites



b) Jack Pine Research Sites



c) Tamarack Research Sites

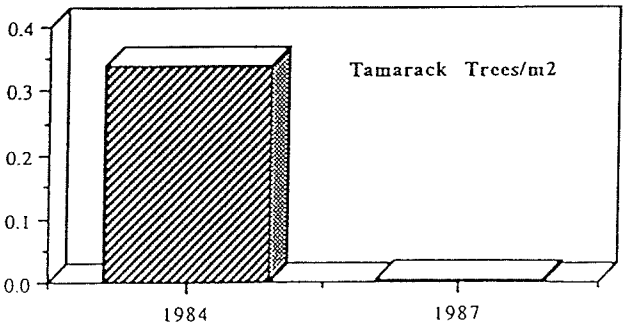


Figure 2.14: Density of sampled trees in ROW research sites. Year of last herbicide application to the site is shown along the horizontal axis. (Densities, given here in trees/m^2, can be multiplied by 10,000 to give trees/ha.)

Jack pine density also increases with time since herbicide treatment: the density of this tree at the SPR (1984) site is 200 trees/ha, more than four times that of the MPR (1987) site, and eight times that of the ES[P]R (1990) site. Tamarack density at the MS[T]R (1987) site is 400 trees/ha compared to 3400 trees/ha at the CTR (1984) site.

Overall, ROW sites range in tree seedling and sapling density from 750 to 11,500 individuals/ha (Table 2.4). Forest sites range between 760 to 4000 mature trees/ha. The majority of ROW sites have a greater tree density than neighboring forest stands; this is due to high sapling survival within the ROW resulting from high available light, space and nutrients and minimal competition from endemic shrubs.

Unsprayed ROW sites are generally lower in tree densities and higher in shrub densities than sprayed ROW sites (Figure 2.15). Shrub species at the two unsprayed shrub carrs (CS[T]U and SPU) reach densities that are well above those found at sprayed ROW sites in the vicinity. The Cranberry Portage sites, being the highest of the sprayed ROW sites in shrub density, reach an average 6200 shrubs/ha. This is lower than the 36,000 shrubs/ha at CS[T]U. Tree density within the unsprayed ROW is only 800 trees/ha compared to 5500 trees/ha within the sprayed ROW. The Sherridon Road unsprayed ROW has 15,000 shrubs/ha compared to 500 shrubs/ha within the sprayed ROW. Tree densities within the ROW are double those found in the unsprayed ROW. The Egg Lake unsprayed site shown in Figure 2.15 is average in both tree and shrub density. However, an adjoining shrub carr of *Betula glandulosa* (see Figure 2. 4) reaches 71,000 shrubs/ha.

SITE COMPARISONS : ORDINATIONS

Principle components analysis (PCA) of the sites based on herbaceous flora shows a separation between bog sites and mineral sites along a soil pH gradient (Figure 2.16). PCA axis 1 represents 37.1% of the cumulative variance and Axis 2 represents an additional 19.2% of the variance. Bog sites such as ESU and CTR are characterized by *Larix laricina*, *Carex* spp. *Vaccinium vitis-idaea*, *Oxycoccus palustris, Caltha palustris, Salix* spp. and *Rubus*

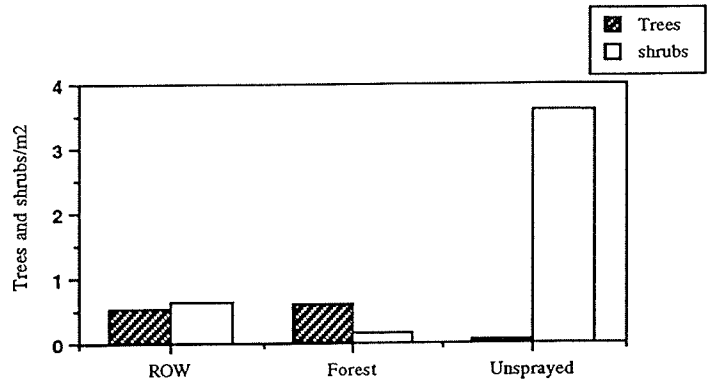
Table 2.4: Density of trees and tall shrubs within the ROW and forest of all research sites. Trees sampled (for mycorrhizae) at each site appear in bold print. (Densities, given in tree/m^2, can be multiplied by 10000 to give trees/ha.)

Site Name (Year sprayed)	Egg Lake Unsprayed (1976)		Cranberry Portage (1984)		Cranberry Portage (1984)		Sherridon Road (1984)		Mafeking (Spruce/tam) (1987)		Mafeking (Pine) (1987)		Egg Lake (Spruce/pine) (1990)	
	ESU*	ESF	CSR	CSF	CTR	CTF	SPR	SPF	MSTR	MSTF	MPR	MPF	ESPR	ESPF
Total Trees/m^2	1.15	0.40	0.32	0.36	0.79	0.34	0.40	.083	0.08	.076	0.43	0.12	.075	0.37
Picea mariana	**0.88**	**0.60**	**0.22**	**0.28**	0.32	0.30	0.09	.005	**0.07**	**.068**	0.01	.006	**0.05**	**0.26**
Larix laricina	0.24	0.20	.002	.006	**0.34**	**.007**	0.00	0.00	**.004**	**.008**	.004	0.00	0.00	0.00
Pinus banksiana	0.00	0.00	.002	.006	0.00	.013	**0.20**	**.073**	0.00	0.00	**0.02**	**0.06**	**.005**	**.004**
Pop. balsamifera	0.00	0.02	0.00	0.00	0.04	.007	0.03	0.00	0.00	0.00	0.01	0.00	0.00	.004
Pop. tremuloides	0.04	0.08	0.02	0.00	.005	0.00	0.07	0.004	.004	0.00	0.38	0.05	0.02	0.10
Betula papyrifera	.009	0.02	0.08	0.00	0.08	.007	0.01	0.00	0.00	0.00	0.005	0.00	0.00	0.00
Salix spp.	0.23	0.67	0.18	0.00	1.03	.007	.004	0.00	0.08	0.00	0.10	0.00	0.02	0.00
Alnus incana	0.00	0.00	0.02	0.07	0.02	.007	0.05	.001	0.00	0.00	0.00	0.00	0.00	0.00

*Site codes are: E: Egg Lake; C: Cranberry Portage; M: Mafeking; S: Sherridon Road; Tree species: S: Spruce; T: Tamarack; P: Pine; R: ROW; F: Forest; U: Unsprayed.

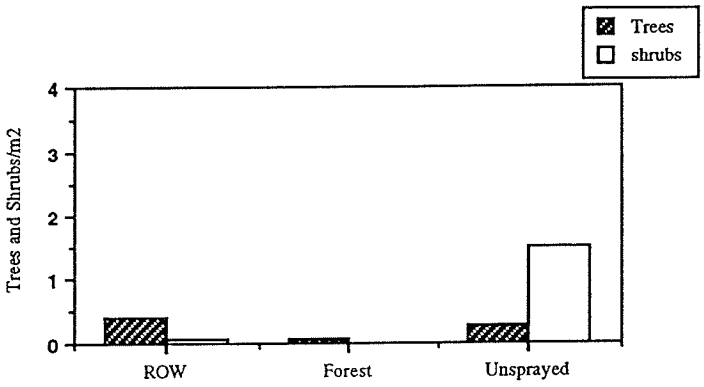
Figure 2.15:
Comparison of tree and shrub densities at three ROW, forest and unsprayed ROW sites. The sprayed ROW's at a) Cranberry Portage, b) Sherridon Road and c) Egg Lake were last treated in 1984 (a and b) and 1990 (c) with *Tordon 101*. The Unsprayed ROW sites have not been treated since an initial application with 2,4-D and 2,4,5-T two years after line clearance in 1976. (Densities, given here in trees/m^2, can be multiplied by 10000 to give trees/ha.)

a) Cranberry Portage Research Sites



*Densities within the ROW are averaged from the spruce and tamarack sites. Forest data is taken from the forest site adjacent to the Unsprayed ROW site.

b) Sherridon Road Research Sites



c) Egg Lake Research Sites

*A shrub carr of Betula glandulosa Michx. within the ROW adjoined to this site reached densities of 7.1 shrub stems/m2 and 0.2 trees/m2.

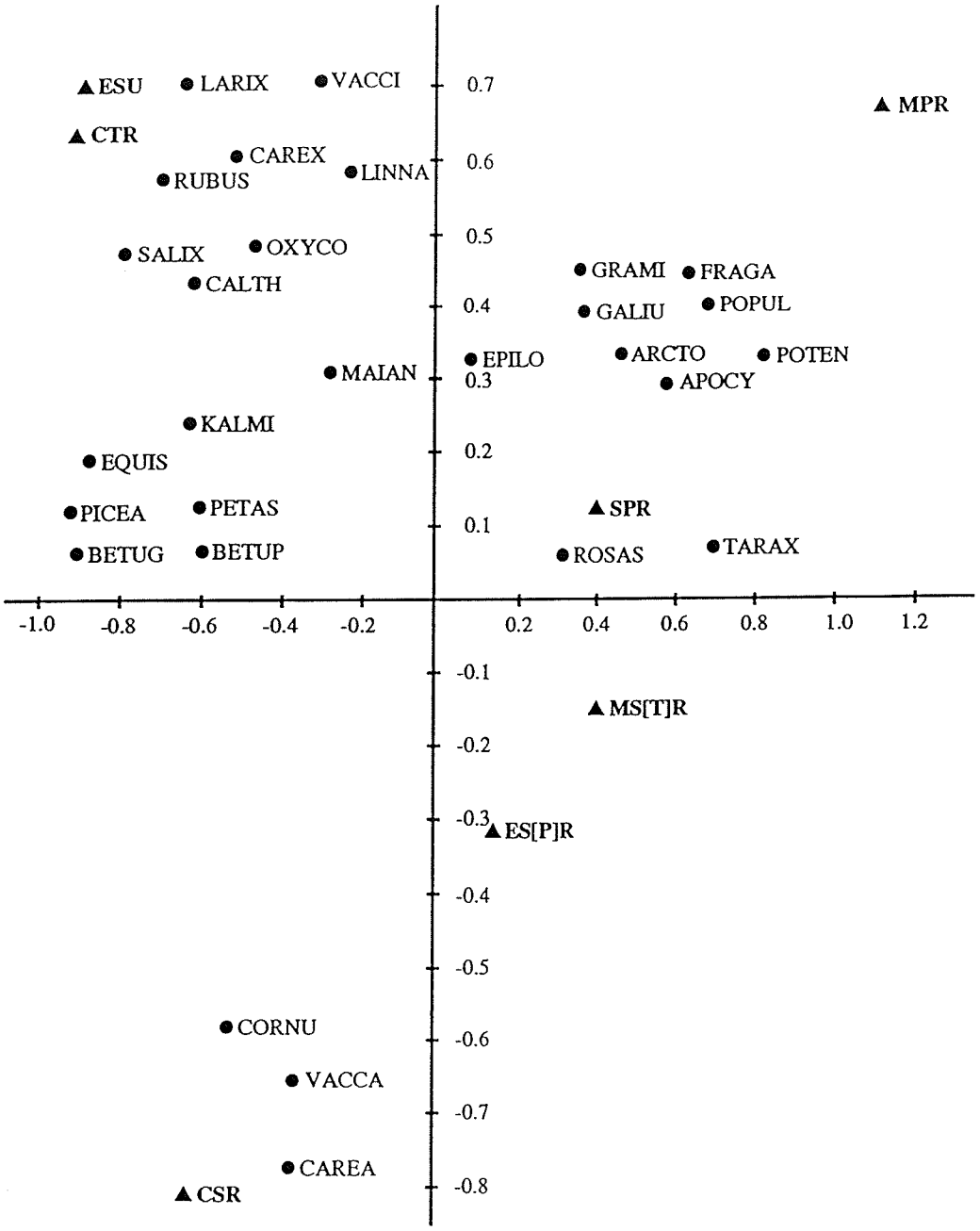
Figure 2.16:
Scatter diagram for 28 plants occurring in two or more ROW sites. The horizontal axis follows a soil gradient ranging from bog soils high in organic matter (left) to mineral and sandy soils (right). The verticle axis corresponds to a pH gradient, ranging from acidic soils (below) to alkaline soils (above).

Sites, indicated by solid triangles (▲), are:

ES[P]R = Egg Lake Spruce and Pine ROW
ESU = Egg Lake Spruce Unsprayed ROW
MS[T]R = Mafeking Spruce and Tamarack ROW
MPR = Mafeking Pine ROW
CSR = Cranberry Portage Spruce ROW
CTR = Cranberry Portage Tamarack ROW
SPR = Sherridon Road Pine ROW

Species, represented by solid circles (●), are:

ARCTO = *Arctostaphylos uva-ursi*
APOCY = *Apocynum androsaemifolium*
BETUG = *Betula glandulosa*
BETUP = *Betula papyrifera*
CAREA = *Carex* cf. *aenea*
CAREX = *Carex* spp.
CALTH = *Caltha palustris*
CORNU= *Cornus canadensis*
EPILO = *Epilobium angustifolium*
EQUIS = *Equisetum* spp.
FRAGA = *Fragaria virginiana*
GALIU = *Galium boreale*
GRAMI = *Graminoid* spp.
KALMI = *Kalmia polifolia*
LARIX = *Larix laricina*
LINNE = *Linnaea borealis*
MAIAN = *Maianthemum canadense*
OXYCO = *Oxycoccus microcarpus*
PETAS = *Petasites sagittatus*
PICEA = *Picea* spp.
POTEN = *Potentilla fruticosa*
POPUL = *Populus tremuloides*
ROSAS = *Rosa* spp.
RUBUS = *Rubus chamaemorus*
SALIX = *Salix* spp.
TARAX = *Taraxacum officinale*
VACCA = *Vaccinium angustifolium*
VACCI = *Vaccinium vitis-idaea*


ESU
LARIX
VACCI
MPR
CTR
CAREX
RUBUS
LINNA
SALIX
OXYCO
GRAMI
FRAGA
CALTH
GALIU
POPUL
EPILO
ARCTO
POTEN
MAIAN
APOCY
KALMI
EQUIS
PICEA
PETAS
SPR
BETUG
BETUP
ROSAS
TARAX
MS[T]R
ES[P]R
CORNU
VACCA
CAREA
CSR
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-1.0
-0.8
-0.6
-0.4
-0.2
0.2
0.4
0.6
0.8
1.0
1.2

chamaemorus. Species common to all bog sites include: *Kalmia polifolia, Equisetum* spp. and *Picea* species while *Vaccinium angustifolium, Cornus canadense* and *Carex cf. aenea* are related to the CSR bog. A separation of the CSR bog site from CTR and ESU occurs along Axis 2 following a pH gradient. The MS[T]R and ES[P]R sites separate out closely along Axis 2 from pine sites (SPR, MPR). These mineral pine sites are characterized by *Graminoid* spp., *Fragaria virginiana, Galium boreale, Arctostaphylos uva-ursi, Potentilla fruiticosa, Apocynum androsaemifolia, Rosa* spp. and *Taraxacum officinale* Species found in both bog and mineral sites include: *Linnaea borealis, Maianthemum canadense* and *Epilobium angustifolium.*

PCA results for woody vegetation composition show site similarities reflecting a soil moisture gradient along Axis 1 from dry (left) to moist (right) (Figure 2.17). Axis 2 separates ROW sites (above) from forest sites (below) with shrub carrs falling centrally. PCA Axis 1 represents 28.2% of the variance and Axis 2 represents 20.2%. Spruce forest sites such as ES[P]F, ESF, CTF, CSF, MS[T]F cluster closely together, being similar in high percent composition of *Picea* spp.. One outlying ROW site, ES[P]R, clusters with the forest sites. Pine sites also cluster and show a clear ROW/forest separation. The spruce ROW sites are more dispersed than the forest sites with CSR (being associated with *Betula papyrifera* and *Salix* spp.) and MPR (high in percent composition of *Populus balsamifera*), being outliers. Sites MS[T]R and ESU are both associated with *Larix laricina* and fall toward the middle of the ROW/forest gradient being intermediate in percent composition of *Picea* spp.. Trembling Aspen, *Populus tremuloides* is strongly associated with pine sites, especially MPR, MPF and SPR.

HABITATS : VEGETATION AND MICROENVIRONMENT

Vegetation analysis of the nine ROW and adjacent forest sites reveals three basic plant communities within the study area related to soil type and moisture. Four sites are located in

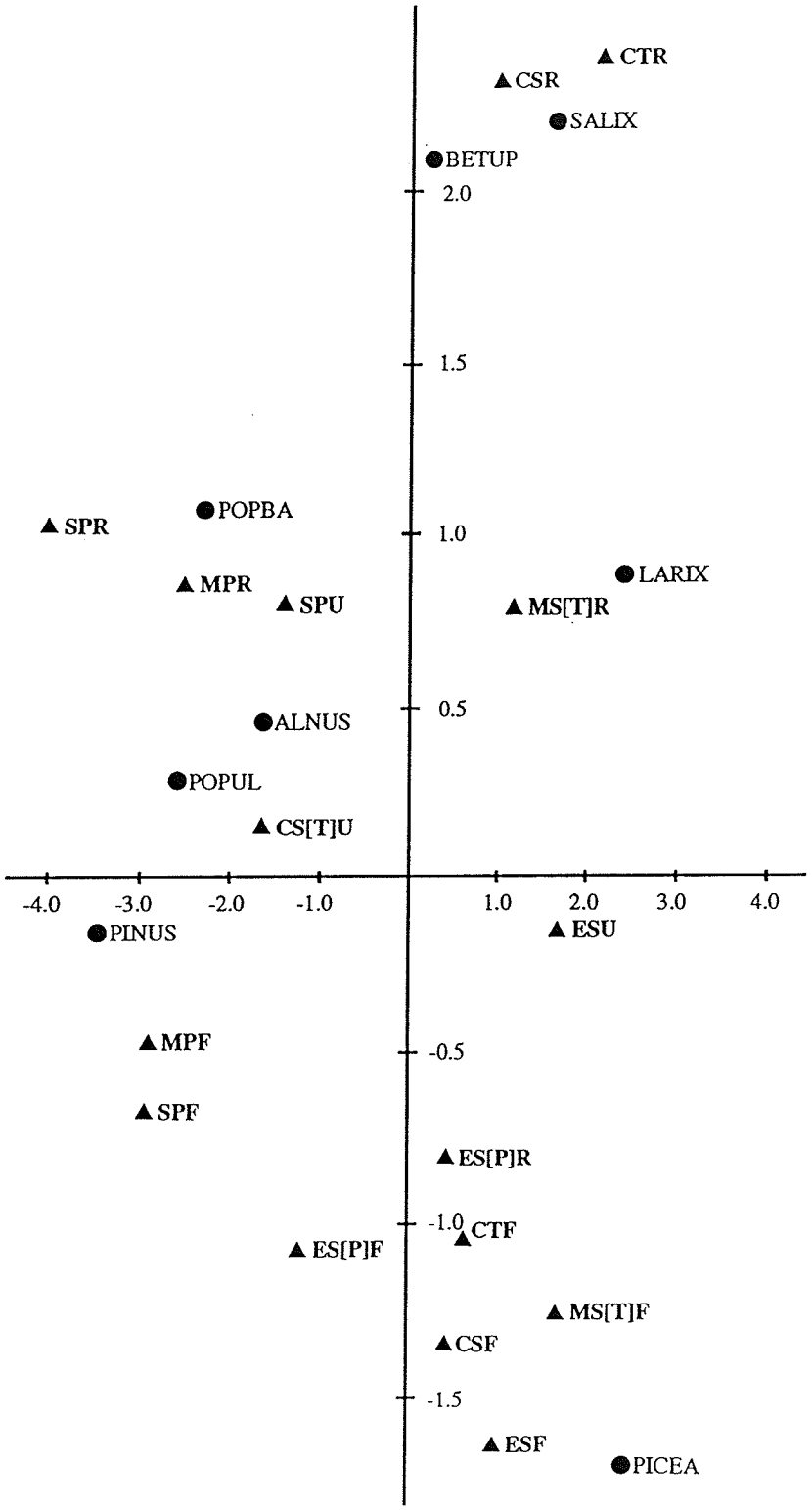
Figure 2.17:
Scatter diagram for woody plants in 16 ROW and forest sites. The horizontal axis corresponds to a soil moisture gradient and represents a change from dry pine sites (left) to moist spruce sites (right). Sites high in alder fall in the middle. The verticle axis separates ROW (above) and forest sites (below).

Sites, indicated by solid triangles (▲), are:

ES[P]R and ES[P]F = Egg Lake Spruce and Pine ROW and Forest
ESU and ESF = Egg Lake Spruce Unsprayed ROW and Forest
MS[T]R and MS[T]F = Mafeking Spruce and Tamarack ROW and Forest
MPR and MPF = Mafeking Pine ROW and Forest
CSR and CSF = Cranberry Portage Spruce ROW and Forest
CTR and CTF = Cranberry Portage Tamarack ROW and Forest
CS[T]U = Cranberry Portage Spruce and Tamarack Unsprayed ROW
SPR and SPF = Sherridon Road Pine ROW and Forest
SPU = Sherridon Road Pine Unsprayed ROW

Species, represented by solid circles (●), are:

ALNUS = *Alnus rugosa*
BETUG = *Betula glandulosa*
BETUP = *Betula papyrifera*
LARIX = *Larix laricina*
PICEA = *Picea* spp.
POPUL = *Populus tremuloides*
POPBA = *Populus balsamifera*
SALIX = *Salix* spp.


CTR
CSR
SALIX
BETUP
2.0
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LARIX
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ALNUS
POPUL
CS[T]U
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
4.0
PINUS
ESU
MPF
-0.5
SPF
ES[P]R
-1.0
CTF
ES[P]F
MS[T]F
CSF
-1.5
ESF
PICEA

spruce/tamarack bog or fen type habitats (CSR, CTR, CS[T]U, ESU), two are on mesic soils in mixed coniferous deciduous forest (MS[T]R, ES[P]R) and three are in dry jack pine forest (MPR, SPR, SPU).

Wet bog sites, having organic, acidic soils, such as CSR, CTR, CS[T]U and ESU are distinguished by high cover of mosses and ericaceous shrubs with black spruce, white spruce, tamarack and willow as the major woody flora. Characteristic herbs include *Equisetum* spp., *Petasites sagitatus, Rubus chamaemorus.* Ericaceous shrubs include *Arctostaphylos uva-ursi, Vaccinium vitis-idaea, Oxycoccus microcarpus* and *Kalmia polifolia.* High cover of *Ledum groenlandicum* at CSR indicates an ombrotrophic (low pH and low Ca) soil and represents a late stage in bog development (Segadas-Vianna 1955; Karlin and Bliss 1984). *Ledum* is reported to have excellent regenerative ability after disturbance, which may explain it's high cover at ESU, CSR and CTR (Jasieniuk and Johnson 1982). The presence of *Chamaedaphne calyculata* at ESU indicates high soil moisture, as this shrub replaces *Ledum* in wet conditions (Dansareau and Segadas-Vianna 1952).

The mesic sites, such as MS[T]R and ES[P]R, having loamy soils, are high in grass cover with an abundance of deciduous trees and shrubs together with *Picea mariana* and *Pinus banksiana.*

Dry sandy sites, such as MPR and SPR, are characterized by high cover of bare ground and lichens with *Populus tremuloides* and *Pinus banksiana* dominating the woody flora. In these sites the herbaceous flora is dominated by graminoid species, *Fragaria virginiana* and *Maianthemum canadense*, species often associated with disturbed habitats.

HABITATS : TEMPORAL ASPECTS

ROW sites sprayed at different times in the past show a progression from grassland/bare-ground to grassland/herb/sapling to young-tree/shrub/herb. Generally, high percentage of bare-ground indicates recent and intense disturbance. Dense grasslands, which

appear in mesic to dry sites are subsequently colonized by trees from between five to 12 years after herbicide application.

Sites Sprayed in 1984

Looking at tree densities within the 1984 spray sites it can be seen that less than a decade is required to produce a dense regrowth of coniferous tree saplings.

Sites Sprayed in 1987

Sites sprayed in 1987 with *Tordon 10K*, a pellet formulation of picloram, are high in cover of grass. Tree densities at these sites are lower than the 1984 sites. Shrubs, with the exception of the ericaceous trailing shrubs *Arctostaphylos uva-ursi* and *Vaccinium vitis-idaea,* which are known for their resistance to picloram, are very low in cover.

Sites Sprayed in 1990

The 1990 spray site at Egg Lake, being almost 70% bare ground and litter shows a virtual absence of broadleaf herbs except for the rare appearance of ruderal species such as *Taraxacum officinale*, *Epilobium angustifolium* and *Ranunculus* spp.

Trends Observed

Several plant species are consistently present in the ROW, as they are dependant on disturbance. *Fragaria virginiana* is the only broadleaf herb to occur at all sites; *Maianthemum canadense*, *Equisetum* spp. and *Epilobium angustifolium* occur at 71% of the sites. *Galium boreale*, an ectomycorrhizal herb, and *Taraxacum officinale* occur at 43% of the sites. These herbs show a resistance to *Picloram* and may indicate herbicide residues.

Judging by the low density and % cover of shrubs within the ROW sites, it would appear that shrubs require more time for recovery from Picloram treatment than target trees. Tree densities recover to reach relatively high densities within seven years indicating a great

need for more comprehensive control of these species. The high frequency (and hence even distribution) of *Ledum groenlandicum* and *Salix* spp. at several of the sprayed ROW sites and the high density of *Alnus rugosa* and *Betula glandulosa* at several unsprayed ROW sites indicates that dense shrublands can be formed within 10 to 15 years if selective vegetation management programs protect these non-targetted species.

Ectomycorrhizal Plants Found Within the ROW

Plants associating with ectomycorrhizal fungi (including ectendomycorrhizal plants), are common in ROW sites and indicate a below-ground density of symbiotic fungi. The most pervasive ectomycorrhizal plants include: the three conifereous trees sampled in this study (*Picea* spp., *Larix laricina* and *Pinus banksiana)* and the ericaceous shrubs common to many sites (*Arctostaphylos uva-ursi, Kalmia polifolia, Ledum groenlandicum* and *Vaccinium* spp.). All members of the following plant families form ectomycorrhizas (although not necessarily only with Basidiomycete and Ascomycete fungi): Cupressaceae (including *Juniperus horizontalis*), Betulaceae (including *Alnus rugosa, Betula glandulosa* and *Betula papyrifera),* and Salicaceae (including *Salix* spp., *Populus balsamifera* and *Populus tremuloides*) (Kendrick 1985). Genera also reported to have ectomycorrhizal species which were found at several ROW sites include: *Shepherdia; Vicia; Fraxinus; Rosa and Galium* (Harley and Smith 1983).

CHAPTER III

ECTOMYCORRHIZAE OF ROW, UNSPRAYED ROW AND FOREST SITES IN NORTH CENTRAL MANITOBA

INTRODUCTION

Fungi in the province of Manitoba have been studied for just over a century and still much remains to be discovered. In 1938, the number of fungi estimated for the province was at least five thousand based on numbers known in Northern Europe, Manitoba collecting records, and comparisons with records of fungi in North Dakota (Bisby et al. 1938). The total number of fungi listed for Manitoba to date is 2,638. One mycologist estimates that at least a third of North American fungal species are as yet undescribed (Phillips 1991). Thus, it is reasonable to assume that the study of fungi in the province of Manitoba is in a similar, incomplete state.

Recent studies confirm that ectomycorrhizal fungi, associated with most coniferous trees, ericaceous shrubs and some deciduous trees, are able to utilize limiting elements from both the organic and inorganic components of the soil via enzymes (i.e. phosphatases, phytases, hydrolases and proteinases) secreted by the fungal symbiont (Cairney and Ashford 1991: Pankow et al. 1991a; Harvey et al. 1976). Ectomycorrhizae facilitate nutrient procurement of trees growing under limiting conditions and are, therefore, a critical component of the Northern Coniferous Forest, the most extensive vegetation zone of Manitoba.

At least 25 families of Basidiomycotina and seven families of Ascomycotina form ectomycorrhizae representing over 500 fungal species (Schenk 1982). Based on root collections, forest sites are generally low in mycorrhizal diversity, ranging from between three to 17 symbionts (Dahlberg and Stenstrom 1991; Danielson and Visser 1989; Danielson and Pruden 1989; Danielson 1984; Shaw and Sidle 1983; Christy et al. 1982). Two or three fungi dominate most sites, augmented by numbers of less frequent symbionts. Relatively few mycorrhizae are found in bog soils where extremes in low soil pH are reached (Jackson and Mason 1984).

Identification of fungal symbionts is usually based on sporocarp collections made in the immediate vicinity of the sampled trees (Jackson and Mason 1984). Because many mycorrhizal fungi do not produce hypogeous fruiting structures, identification of mycobionts can be difficult without verifiable fruiting body association. High fruiting body diversity within forest stands, often ranging between 20 to 60 species, can also confuse the process of identification. In some cases, attributes of the sheathing mycorrhizas, which are known to be constant, may be used (Thomas and Jackson 1979). Root modifications of a given mycorrhizal fungus may differ between tree species, however, mantles, radiating hyphae and rhizomorphs remain similar between trees. Identification of mycobionts is clearly the most difficult task in a mycorrhizal study. Keys based on the gross morphological characteristics of mycorrhizas are currently being compiled to facilitate this task (Agerer 1987).

In this study, mycorrhizae are described. This research provides new data on the mycological community of ROW habitats as well as additional information on the mycorrhizal status of coniferous trees of Manitoba.

METHODS

Mycorrhizal Sampling

At each research area (i.e. Cranberry Portage, Sherridon, Mafeking, Egg Lake) ten seedling root systems of each tree species were randomly collected from the sprayed ROW, unsprayed ROW and adjacent forest. Roots, to a depth of approximately one foot, and the associated mycorrhizae were carefully extracted from the soil within a radius of 25cm of the seedling stem. Root samples were washed with tap water and feeder roots were removed from the root mass. Samples were placed in 15ml test tubes and fixed in 50% ethanol prior to microscopic examination (after Koske and Gemma 1989). These samples were placed in a gridded petri dish to determine the percent infestation of the different types of mycorrhizae. Fifty root tips were randomly scored per root system. Only intact short roots were evaluated.

Chlorazole Black E (C.I. 30235) stain was used in microscopic (40x and 100x) confirmation of hartig net formation by mycorrhizae.

Mycorrhizal Identification

Differences in color (white, yellow, pink, beige, brown, grey, black, etc.) texture (coarse, smooth, crystalline, mucilaginous), type of root modification (simple, clubbed, bifurcate, pinnate, tuberculate, coralloid) and presence of radiating hyphae and rhizomorphs were noted as distinguishing characteristics for each mycobiont. Taxonomic handles (i.e. White Mycorrhiza, Pink Mycorrhiza, etc.) were given to the unidentified species based on color and other notable characteristics.

Mushroom Collections

The ROW and forest were surveyed for fungal sporocarps in late September 1991. The collections, taken along 23m long belt transects, were considered to indicate possible mycotrophs associated with the root samples. Numbers of mushrooms per transect were recorded. Nomenclature of fungi follows Phillips (1991) and Dickinson and Lucas (1979).

RESULTS

Out of the three hundred and twenty-five tree seedlings sampled in the study, representing a total of 16,250 scored root tips, twelve different symbionts were distinguished (Table 3.1). Percent presence of each mycorrhizal type, as well as morphological characteristics, differentiate the symbionts. Several different mycorrhizas were found in the study, although only two were ubiquitous. Following are brief descriptions of each of the 12 symbionts observed in this survey. The most frequently encountered mycorrhizae and root modifications observed in the study are shown in Figures 3.1 - 3.6. Hartig net formations of the mycotrophs within the root cortex confirm their identity as mycorrhizal (Figures 3.7 - 3.11).

Table 3.1. Description of mycorrhizae associated with spruce, jack pine and tamarack seedlings collected at twenty sites in North-central Manitoba in June of 1991. Percent presence (%P) of each mycorrhizal type, as well as morphological characteristics such as color, texture, root modification, presence of radiating hyphae and rhizomorphs are indicated. Percent presence is calculated as the number of sites of occurence of each mycorrhizal type divided by the total number of sites (x 100).

Mycorrhizae	%P	Color	Texture	Modification	Hyphae	Rhizomorphs
Cenococcum sp.	100	Black	Coarse	Simple	Stiff, radiating	None
White	100	White/off-white	Smooth	Pinnate/tuberculate	None	Present
Soft-white	65	Powdery white	Smooth	Simple/clubbed	None	None
Brown	60	Medium brown	Coarse	Simple/bifurcate	Fine	None
Beige-tan	45	Beige/tan	Wooly	Clubbed	Coarse	None
White-yellow	25	Yellowish white	Wooly	Simple/clubbed	Fine/gossamer	None
Piloderma sp.	20	Sulphur yellow	Muscilagenous	Simple/clubbed	Clumped	Present
Angel-white	20	White	Wooly	Simple/clubbed	Fine/gossamer	None
Grey	20	Light grey	Coarse	Simple	Coarse	None
Clear	15	Transluscent	Coarse/crystaline	Simple/clubbed	None	None
Bright White	5	Luminescent white	Smooth	Simple/clubbed	None	Present
Pink	5	Light Pink	Muscilagenous	Clubbed	Clumped	Present

Mycorrhizae Collected

Cenococcum geophilum Fr.

Cenococcum geophilum Fr., found at 100% of the ROW, forest and unsprayed sites, is characterized by black, simple, often club shaped mycorrhizae with stiff black-brown hyphae radiating out from the mantle (Figure 3.1).

Piloderma croceum (Peck) Julich

Piloderma croceum (Peck) Julich, is easily distinguished by its bright yellow color and distinctive mucilaginous hyphae and rhizomorphs. It is found in 20% of the collection sites associated with spruce and jack pine. Root modifications are simple to club shaped (Figure 3.1). *Piloderma* forms a thick sheath and mantle around the root and penetrates very little into the root cortex (Figures 3.7 and 3.9).

White Mycorrhiza

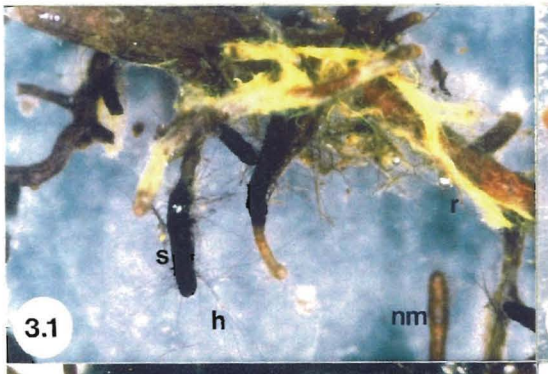
Often producing pinnate and tuberculate root modifications, this mycorrhiza is found in all sites. Rhizomorphs interconnect the root tips. This mycorrhiza is white to off-white, smooth and devoid of hyphal strands. In this study, White Mycorrhiza is most generally associated with tamarack roots as white pinnate and tuberculate mycorrhizal form modifications (Figures 3.2 and 3.5). However, this is also associated with spruce and pine. White Mycorrhiza has a dense sheath with shallow penetration of hyphae into the outer root cortex (Figures 3.10 and 3.11).

Soft White Mycorrhiza

Soft White Mycorrhiza is found at 65% of the collection sites in association with all tree species. The sheath is powdery-white, smooth, often club shaped with no hyphal strands or rhizomorphs (Figure 3.3). Soft White Mycorrhizae is not as shiny in appearance as the White Mycorrhiza and appears more firm in texture.

Figures 3.1 - 3.6.

Mycorrhizae and root modifications of spruce, tamarack and jack pine. Fig. 3.1. Black sheath (s) and radiating hyphae (h) of *Cenococcum geophilum* Fr., non-mycorrhizal roots (nm) and yellow rhizomophs (r) of *Piloderma croceum* (Peck) Julich associated with spruce (20x mag.). Fig. 3.2. Typical pinnate root modification of tamarack associated with White Mycorrhiza (20x mag.). Fig. 3.3. Soft White Mycorrhiza forming club shaped modification with tamarack (64x mag.). Fig. 3.4. Brown Mycorrhiza forming clubbed (c) and bifurcate (b) root modifications with spruce. Fig. 3.5. Dense tuberculate root clusters (cl) of White Mycorrhiza associated with tamarack. Fig. 3.6. Bulbous root modifications (bu) of Brown Mycorrhiza common to spruce and jack pine seedling roots (28x mag.).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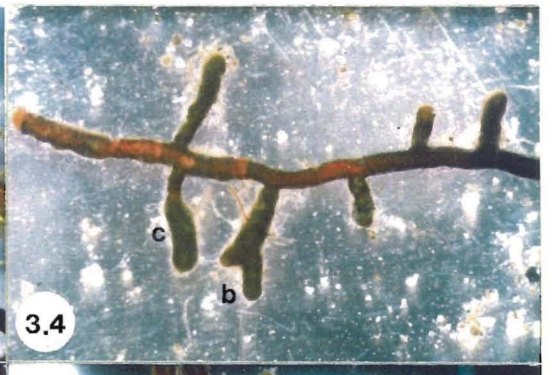
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cl
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c
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bu
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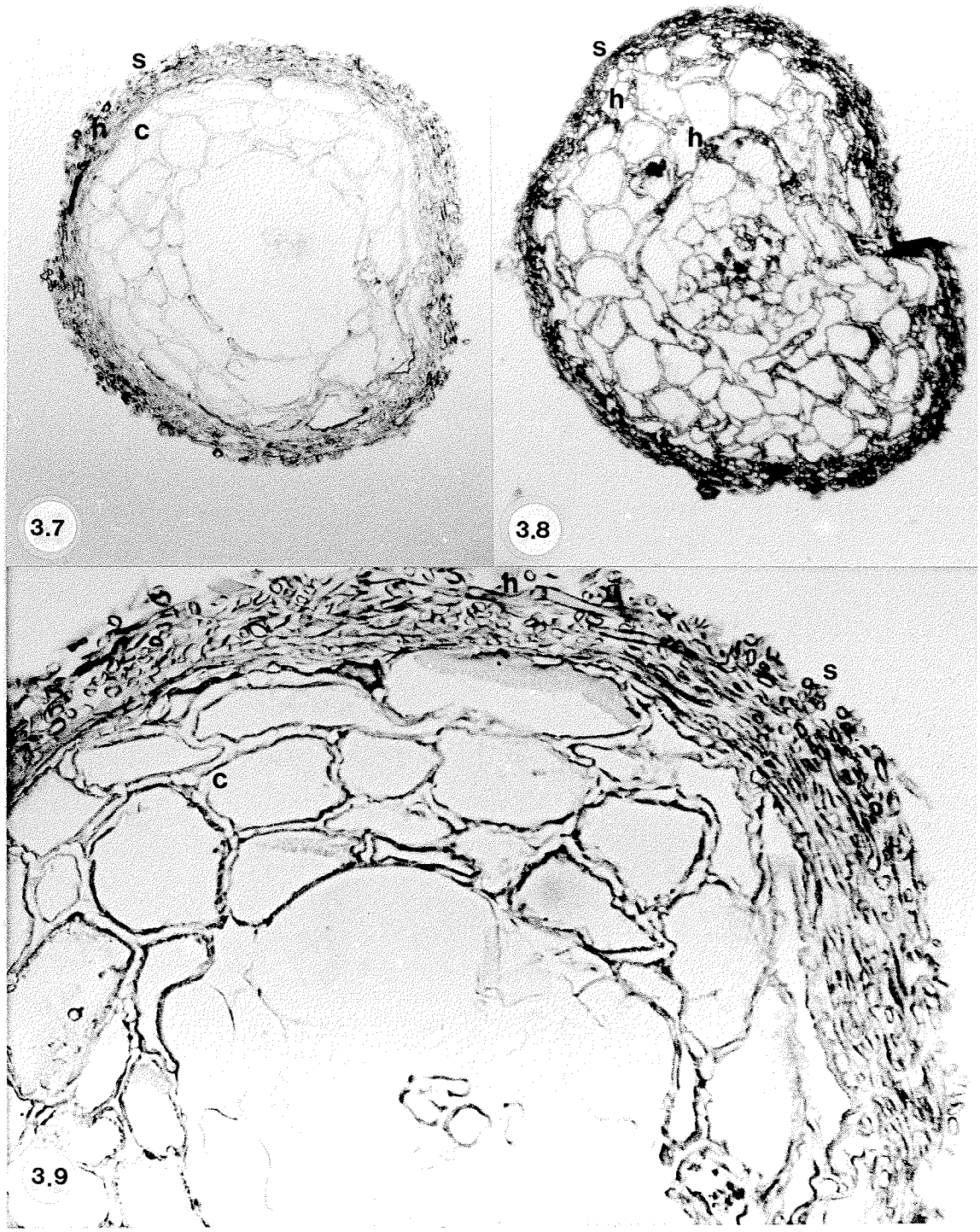
Figures 3.7 - 3.9.

Cross sections of spruce sapling roots collected in July 1991 showing hartig net formations of different symbionts stained with Chlorazole Black E (Sigma C.I. 30235). Fig. 3.7. *Piloderma croceum* mycorrhiza showing a thick sheath (s) of hyphae (h) surrounding the root cortex (c) (200x mag.). Fig. 3.8. Sheath (s) and hartig net (h) formed by Brown Mycorrhiza (200x mag.). Fig. 3.9. Sheath (s) and sheath hyphae (h) of *Piloderma croceum* magnified (1000x mag.).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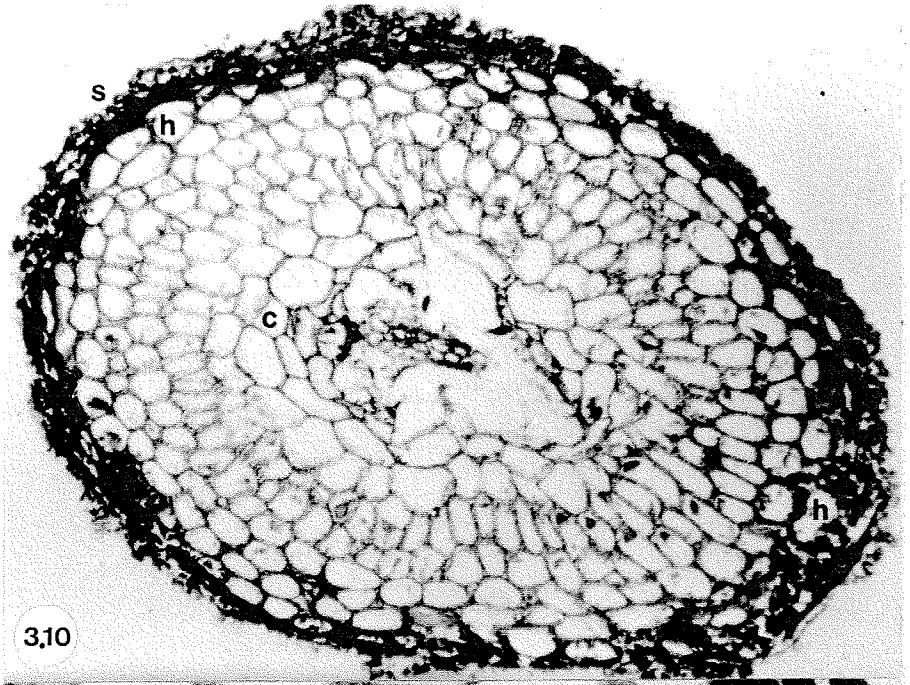
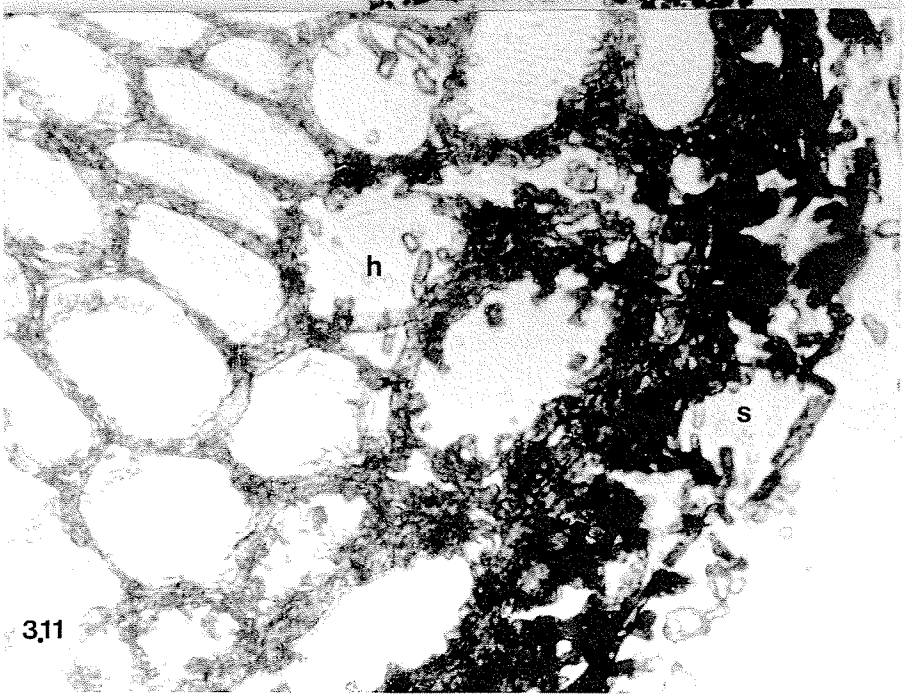
Figures 3.10 - 3.11.

Cross sections of White Mycorrhiza of spruce collected in July 1991 stained with Chlorazole Black E (Sigma C.I. 30235). Fig. 3.10. The thick sheath (s) is clearly visible, with slight penetration of hyphae (h) to the second and third cortical cell layers (c) (200x mag.). Fig. 3.11. Sheath (s) and hartig net (h) of White Mycorrhiza magnified (1000x mag.).



3.10



3.11

Brown Mycorrhiza

Brown Mycorrhiza, found at 60% of the collection sites, is medium brown to tan. Roots associated with this symbiont are simple to bifurcate shaped (sometimes bulbous as in Figure 3.6) and appear to have no rhizomorphs associated (Figure 3.4). On the roots the sheath is coarse with fine, hair-like hyphae radiating out from the mantle. This symbiont shows a dense sheath with penetration of hyphae to the third cortical cell layer (Figure 3.8).

Beige Mycorrhiza

Beige mycorrhiza, found in 45% of the collections, is associated with all three target trees and forms simple to club shaped mycorrhizae. The mycorrhizae are wooly with hyphal strands and there is no evidence of rhizomorphs being present.

Yellowish-White Mycorrhiza

Yellowish-White Mycorrhiza possess fine hyphae and no rhizomorphs. This mycorrhiza is found in 25% of the collections in association with all three target trees. The mycorrhizae are simple to club shaped.

Angel-White Mycorrhiza

This mycorrhiza, characterized by wooly or angel hair-like radiating hyphae, is found in 20% of the collections on roots of all target tree species. A white, loose sheath with radiating hyphae covers simple to club shaped roots.

Grey Mycorrhiza

A smooth, simple, light-grey symbiont appears in 20% of the sites on the roots of all three types of trees. No rhizomorphs or radiating hyphae are observed.

Clear Mycorrhiza

A clear, crystalline textured symbiont appears in 15% of the sites. The sheath is translucent covering club shaped roots. No hyphal strands or rhizomorphs appear to be formed.

Bright-white Mycorrhiza

A luminescent white symbiont with rhizomorhps is associated with tamarack seedlings in 5% of the sites. The mycorrhizae are smooth and simple to club shaped.

Pink Mycorrhiza

A pink symbiont is found in 5% of the sites associated with jack pine seedlings. The mycorrhiza is mucilaginous, simple to club shaped and has a thick mantle and abundant rhizomorphs.

Mushroom Collections

Mushroom fruiting is considerably suppressed within the ROW habitat compared to the forest sites (Table 3.2). Collections among the sites varied significantly in species composition and numbers of individuals. Mycorrhizal fungi of the genus *Cortinarius* were the most prevalent over all the sites. *Cortinarius semisanguine*, with its deep red gills, and *C. glaucopus*, characterized by a lavender stipe, are easily identified. Other *Cortinarius* specimens are either questionably named to the species level or are identified only to genus.

Regarding the density (either total or specific) of mushrooms it is interesting to note that there are site differences. The Cranberry Portage spruce and tamarack forest sites have an elevated total density of fungi. *Russula delica*, *R. emetica*, *Entoloma salmoneum*, *Hygrophorus borealis* and several *Cortinarius* spp. are the most commonly encountered fungi in the Cranberry Portage forest sites. The Sherridon Road and Mafeking pine forest sites have high densities of *Hydnellum diabolus*, a large dark brown dogtooth-fungus known to be mycorrhizal and *Coltricia perennis*, a white and grey ringed polyporus mycorrhizal fungus.

Table 3.2: Mushroom fruiting bodies collected at all research sites in September 1991. (Nomenclature after Phillips, 1991 and Dickinson and Lucas, 1979.) (Asterisk denotes known mycorrhizal fungi.)

Mushrooms Identified	Cranberry P.		Sherridon Road			Mafeking		Egg Lake		
	CSTR	CSTF	SPR	SPU	SPF	MPF	MSTF	ESPR	ESPF	ESU
**Cystoderma amianthinum* (Scop. ex Fr.)				8						
Lyophyllum (loricaetum ?)		14								
**Melanoleuca (alboflavida ?)*									1	
**Clitocybe clavipes* (Fr.) Kummer							3			
Collybia platyphylla (Fr.) Kummer		1								
Collybia dryophila (Bull. ex Fr.) Kummer		5								
**Hygrophorus borealis* Pk.		11	1				2			11
**Hygrophorus bakerensis* Smith & Hesler									4	
**Hygrophorus* spp.							2			4
Marasmius (ramealis ?)		8								
Marasmius rotula (Fr.) Kummer		27								
Marasmius spp.							1			2
**Omphalina (rustica ?)*		1							1	
Rickenella fibula (Bull. ex Fr.)				1						
Mycena spp.		28	3						5	2
**Russula delica* Fr.		2								
**Russula emetica* (Fr.) Pers.		1						2		
**Entoloma salmoneum* (Pk.) Sacc.		3							1	
**Cortinarius semisanguine* Fr.	2									
**Cortinarius glaucopus* Schaeff. ex Fr.		1		2					3	
**Cortinarius (cinnamomeus ?)*									46	
**Cortinarius (cinnabarinus ?)*	1			11			4			
**Cortinarius (androsaceus ?)*		14								
**Cortinarius* spp.		4		2				4	4	
Pholiota spp.		1								
Conocybe crispa (Longyear) Singer		1								
Galerina cerina Smith and Singer		6								
Naematoloma (epipteryzia ?)		1								
**Ripartites tricholoma* (Fr.) Karsten									1	
Psathyrella spp.		1								
Coprinus atramentarius Fr.									2	
**Cantharellus umbonatus* Fr.				5						
**Coltricia perennis* (Fr.) Murr.			5		1		2			
**Hydnellum diabolus* Banker					3	15				
Unknown Fungi				2			1		7	

[1]Site codes are: E: Egg Lake; C: Cranberry Portage; M: Mafeking; S: Sherridon Road; Tree species: S: Spruce; T: Tamarack; P: Pine; Collection site: R: sprayed ROW; F: Forest; U: Unsprayed ROW.

The Sherridon Road unsprayed site is dense in *Cystoderma amianthinum*, various cob-web-veiled *Cortinarius* spp. and *Cantharellus umbonatus*. The Mafeking spruce and tamarack forest site is colonized by *Clitocybe clavipes*, a previously documented mycorrhizal fungus in Manitoba (Brisby et al. 1938). Other mycorrhizal fungi, typical in the Mafeking spruce and tamarack sites, include *Hygrophorus* and *Cortinarius* species. The Egg Lake spruce and pine sites are high in *Hygrophorus* spp., such as *H. borealis* and *H. bakerensis*; *Cortinarius* spp. and several unidentified fungi.

DISCUSSION

Mycorrhizae Identified

In my study, the ascomycete *Cenococcum geophilum* Fr. was found to be the dominant mycobiont associated with spruce, jack pine and tamarack in north and central Manitoba. Its distinctive black sheath and radiating hyphae make it easily identifiable. Other studies in the boreal forest of North America and elsewhere, document presence of this mycorrhiza (Harvey et al. 1976; Harvey et al. 1978; Massiotte et al. 1992). It is especially important in upland sites where temperatures reach extremes (Erland and Soderstrom 1991; Shaw and Sidle 1983; Christy et al. 1982). Sclerotia of this fungus give it a competitive edge through broad distribution mitigated by wind and mammal vectors and increased survival throughout the long winter (Maser et al. 1978; Wilde 1963).

The next most prevalent mycorrhiza in my study area is the White Mycorrhiza. This mycorrhiza is possibly formed by fungi of the genus *Cortinarius* which are the most numerous of all mushrooms found in my survey. An unidentified mycorrhiza, having smooth white sheath with rhizomorphs and the typical pinnate root modifications of my mycorrhizal material, dominates Montana forests (Harvey et al. 1976; Harvey et al. 1978). *Cortinarius* mycorrhizae of *Picea abies* (L.) Karst. show similar color and gross morphological attributes (Agerer 1987) to my material. White mycorrhizae are also formed by *Russula* species such as

R. emetica (Fr.) Pers. and *R. delica* Fr.. (These *Russula* species are also found in this study, but at much lower frequencies than *Cortinarius* spp.).

Philoderma croceum (Pk.) Julich (syn. *Corticium bicolor* Peck.), found at four bog and other moist boreal sites in my study, is known for being acidophillus, and sensitive to competition from other symbionts especially *Cenococcum* sp. (Erland and Soderstrom 1991). This sensitivity to competition may explain its low frequency at many of my study sites. In central Manitoba, distribution of *Piloderma* is much less uniform than either *Cenococcum* or the White Mycorrhiza. Material of *P. croceum* has previously been identified in coniferous woods of Manitoba (Brisby et al. 1938).

There are a number of fungi which may be responsible for forming the brown, beige and some of the other mycorrhizae described in this study. *Hygrophorus* spp., common to many of my study sites, may participate in forming mycorrhizae typical of my Brown and Beige mycorrhizae. Other mushrooms forming similar mycorrhizae include: *Hebeloma, Inocybe, Gomphidius, Lyophyllum, Tricholoma, Cantharellus, Omphalina* and *Hydnum* (Harley and Smith 1983). *Marasmius*, although not normally listed as mycorrhizal, does include one species, *M. oreades* Fr., reported to form ectomycorrhizae with *Pinus ponderosa* Laws. (Kelley 1950). More detailed studies are needed to confirm the interaction of other *Marasmius* species with coniferous trees. It is interesting to note that *Marasmius rotula* is one of the most abundant mushrooms in spruce and tamarack forests of the Cranberry Portage research sites.

Mycorrhizae of Northern Forests

Cenococcum geophilum and *Piloderma croceum* are common mycorrhizae of *Pinus sylvestris* L. seedlings in cold boreal forests and clear-cuts of central Sweden (Dahlberg and Stenstrom 1991). *Cenococcum geophilum* is prevalent at planting sites and clear-cuts of

southeast Alaska (Shaw and Sidle 1983). The predominance of these cold-loving (cryophillic) fungi in Manitoba is therefore not unexpected.

Ectomycorrhizae of Western hemlock, *Tsuga heterophylla* (Raf.) Sarg. in the Cascade mountains of Oregon include *Cenococcum geophilum* Fr., *Piloderma croceum* (Bres.) Erikss. & Hjorts., and four unidentified symbionts described as tan, pale yellow, white crustose and white mat (Christy et al. 1982). Two thirds of the Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco) mycorrhizae of the same region are formed by *Rhizopogon* species. The sheath of this mycorrhiza is described as white to brown or black with a granular or crystalline texture, and having single to pinnate or tuberculate root modifications with many rhizomorphs. An unidentified brown mycorrhiza (golden brown, smooth, single to pinnate mycorrhizae without rhizomorphs) and *Cenococcum* sp. (jet black, simple mycorrhizae with coarse radiating hyphae) are also documented. In Western Hemlock forests, twelve ectomycorrhizal types can be distinguished (Pilz and Perry 1984).

In northern Minnesota, ectomycorrhizae associated with black spruce include *Cenococcum* sp. (simple, black), *Laccaria bicolor* (Maire) Orton (simple, smooth pale orange-brown), *Laccaria laccata* var. *moelleri* Singer (simple, smooth, pale orange-brown), *Rhizopogon* sp. (coralloid, white to creamy white) and *Suillus cavipes* (Opat.) Smith & Thiers. (racemose, white to creamy white becoming gray with age) (Doudrick et al. 1990).

Ectomycorrhizae in jack pine forest stands of northeastern Alberta include: *Tricholoma* spp., *Suillus* spp., *Cenococcum geophilum, Laccaria* sp., *Scleroderma* sp., *Astraeus* sp., *Lactarius* sp., *Coltrichia perennis* Fr. Murr., and *Bankera* sp. (Danielson 1984). Sporocarps found almost exclusively in mature forest stands include species of the genera: *Elaphomyces, Suillus, Cortinarius, Cantharellus*, and *Hydnellum*. Disturbed sites were colonized by *Laccaria sp., Rhizopogon rubescens* Tul., *Scleroderma sp.* and *Astraeus hygrometricus* (Pers.) Morgan. Many of the genera listed in this study of the Alberta jack pine forest (inc. *Tricholoma, Cenococcum, Coltrichia, Cortinarius, Cantharellus* and *Hydnum*) are also reported in my study of Manitoba forests.

Urban spruce of Calgary, Alberta, were commonly associated with E-strain (Complexipes), (inoculated in nurseries) which formed a third of the mycorrhizae (Danielson and Pruden 1989). Greater than 5% of the mycorrhizae were formed by *Amphinema* sp., a whitish to yellow symbiont. White to tan mycorrhizae, pallid to dark reddish brown mycorrhizae and dark brown mycorrhizae accounted for 30% of the sheathed root tips. Over 20 other mycorrhizas were observed, which, with the exception of *Cenococcum geophilum*, could not be identified. Similar attributes of unidentified symbionts can be found in mycorrhizae of my study, as refers to the White-Yellow Mycorrhiza, White to Beige Mycorrhiza and Brown Mycorrhiza.

Cortinarius pholideus Fr., *Lactarius helvus* Fr. and *Russula venosa* Fr. are known to colonize spruce in bog sites where extremes in low soil pH favour development of relatively few sheathing mycorrhizas (Jackson and Mason 1984). In peatlands of northern Minnesota, *Rozites caperata* (Pers. Fr.) was the most frequent fungal species collected (Doudrick et al. 1990). *Cantharellus infundibuliformis* (Scop.) Fr., *Russula paludosa* Britz. and *Amanita vaginata* (Fr.) Vitt. were also present. Contrary to other studies (Dighton 1991; Dahlberg and Stenstrom 1991), *Cortinarius* spp. were only found in old forest stands of this survey.

Mycorrhizal Host Range and Inoculum

As stated previously in the introduction of this thesis, numerous ectomycorrhizal fungi associated with conifers also form ectendomycorrhizae with a wide range of ericaceous shrubs (Schenk 1982). The broad host range of *Cenococcum* sp., *Cortinarius* spp. and *Piloderma* helps to explain the high incidence of occurrence of these symbionts at many of my study sites where there is a high density of host roots for colonization, especially in the forest (MacLellan 1982).

At older ROW sites, there is often an abundance of these low and trailing shrubs. (The reader may wish to consult Chapter II of this thesis to address this point.). Roots of these shrubs, which may survive or recover from herbicide application, function to supply

inoculum, or living mycelium, for mycorrhizal infestation of target trees. Albeit that target tree colonization may be enhanced by presence of such mycorrhizal inoculum, evidence indicates that these shrubs are able to out-compete target trees if left untreated on the ROW (Bramble and Barnes, 1990) and provide valuable feeding habitat to wildlife (Bramble et al. 1991; Bramble et al. 1985).

CHAPTER CONCLUSION

Further research is needed to identify many of the mycorrhizas encountered in this study. Rigorous protocols are required to prove that a given sporophore is mycorrhizal with a given tree species. To begin, pure cultures of ectomycorrhizal fungi must be maintained for the inoculation of sterile tree seedlings. Fungi can be cultured in liquid nutrient media for this purpose and incubated in a moist peat/vermiculite substrate (Schenk 1982). The development of a working system for the germination and growth of trees under sterile conditions and for their inoculation with mycorrhizal fungi without contamination is, in itself, a timely procedure. Once a mycorrhizal interaction is established, the fungus must be re-cultured from the roots and shown to be the same as the original isolate. This isolate must then be used to re-establish a mycorrhizal formation with sterile seedlings .

In my study, specific attributes of twelve mycorrhizas were documented. This data may be used as a reference point for further work on mycorrhizae in Manitoba's Northern Coniferous Forest.

CHAPTER IV

MYCORRHIZAL ASSOCIATIONS OF BLACK SPRUCE, JACK PINE AND TAMARACK IN HYDRO CORRIDORS OF NORTH-CENTRAL MANITOBA MANAGED WITH *PICLORAM* AT DIFFERENT TIMES IN THE PAST

INTRODUCTION

Many herbicides are toxic to the symbiotic fungi associated with tree roots (Chakravarty and Chatarpaul, 1990; Chakravarty and Chatarpaul, 1988; Trappe et al., 1984; Nemec and Tucker, 1983; Trappe, 1983; Kelly and South, 1980; Marx et al., 1978). The phenoxy herbicide *triclopyr* is toxic to the ectomycorrhizae of lodgepole pine (*Pinus contorta* Dougl.) and white spruce (*Picea glauca* (Moench) Voss); at concentrations of 1ppm, inhibition of growth of *Suillus tomentosus* (Kauf.) Snell, Singer and Dicks is observed and at 10ppm mortality occurs (Sidhu and Chakravarty 1990). Certain herbicides selectively inhibit the ericoid fungi associated with heath shrubs which are also ectomycorrhizal (Litten 1985).

Generalizations about each herbicide's toxicity relative to specific symbionts, however, cannot be made. In certain cases, trees infested by ectomycorrhizae are more sensitive to herbicides, while in other situations the fungi are seen to protect plants from herbicide toxicity. As such, ectomycorhizal fungi may be used as biological 'buffers' to herbicide effects (Siqueira et al. 1991). Some fungi are even stimulated by these compounds and can utilize them as a nutrient source (Smith and Ferry 1979). The phenoxy herbicides 2,4-D, 2,4,5-T and MCPA are known to stimulate mycorrhizal species including *Boletus variegatus, Boletus luteus* and *Rhizopogon roseolus* at low concentrations (10ppm) while inhibiting growth at higher concentrations (100 to 250ppm) (Dasilva et al. 1977).

Herbicide effects on mycorrhizal fungi can influence target tree succession and are important to consider in site management planning. Forestry practices aim to enhance mycorrhizal inoculum at cleared sites, while Hydro ROW management would presumably benefit from diminished levels of ectotrophic fungi. Different management practices may be used to achieve these ends. Understanding the impact of spray programs on the density of mycorrhizal fungi within treated sites can result in more effective management. Comparing infestation levels of sites treated with manual and chemical methods at different times in the past can tell us much about the long-term benefits of each method.

MATERIALS AND METHODS

Study Site Selection, Management Regimes and Abbreviations

ROW sites treated with *Tordon 101* (Cranberry Portage 1984; Sherridon Road 1984; Egg Lake 1990) and *Tordon 10K* (Mafeking 1987) were chosen to examine target tree regrowth and mycorrhizal colonization of seedlings within these sites. Sites were chosen according to the types of target trees present in the ROW, herbicide formulation used and time since herbicide treatment.

The corridors studied were originally cleared in 1974/1975, except for the Mafeking line which was cut in 1967. Two years after clearance the corridors were treated with a mixture of 2,4-D and 2,4,5-T. The reader may wish to consult Chapter II of this thesis for explanation of site abbreviations used in this chapter. Also, site names and abbreviations are given in Appendix II.

Mycorrhizal Sampling

Ten seedling root systems of each of the three target species were randomly collected from sprayed ROW, unsprayed ROW (where possible) and adjacent forest sites (i.e.. Cranberry Portage, Sherridon, Mafeking, Egg Lake and Waterhen). Feeder roots and mycorrhizae were carefully extracted from soil collected within a 30cm radius of the stem to a depth of approximately 30cm. All roots were washed with tap water and fixed in 50% ethanol (Koske and Gemma 1989) before examination. Feeder roots from each sample were placed in petri dishes and examined microscopically to generally characterize the mycorrhizae. Each of the mycorrhizae are characterized in Chapter III of this thesis. Fifty root tips were scored per root system (using a line/intersect grid) for percent infestation of each mycorrhizal type. Only intact short roots were evaluated. Chlorazole Black E stain (Sigma C.I. 30235) was used to confirm hartig net formation of the mycotrophs using cross sections of root tips under 40x to 100x light microscope magnification.

RESULTS

Mycorrhizal Infestation Levels

Forest saplings of all three tree species have sheathed tip levels ranging between 35.2 ± 6.7% and 75.4 ± 3.5% with a mean for all forest sites of 59.6 ± 5.0% (Figure 4.1). ROW saplings range between 22.2 ± 3.1% and 72.6 ± 4.7%. Excluding the Mafeking collections, the ROW mean is 28.5 ± 2.6%, over 30% lower than the forest mean. When the Mafeking sites are included, the ROW mean is 40.2 ± 6.37%. Unsprayed sites range between 27.8 ± 3.2% and 55.1 ± 5.4% with a mean of 39.1 ± 4.9%.

The reader may wish to consult Appendix IV for information on mycorrhizal infestation levels of individual tree root systems.

Site Mycorrhizal Attributes

In the following descriptions, the mycorrhizal flora of each site is described in terms of the total number of different symbionts identified at the site and the intensity of mycorrhizal infestation by each symbiont with the tree species. Table 4.1 lists the percentage of seedlings colonized by each symbiont per site. In this table, the sites are presented in order of increasing number of symbionts identified at the sites, with ROW bog sites at Cranberry Portage being the lowest in mycorrhizal diversity and Mafeking and Sherridon Road forest sites being the highest in diversity. In Figure 4.2, sites are arranged in increasing order of percent infestation with *Cenococcum geophilum.* Spruce root systems tend to be less infested with *C. geophilum* than Pine roots.

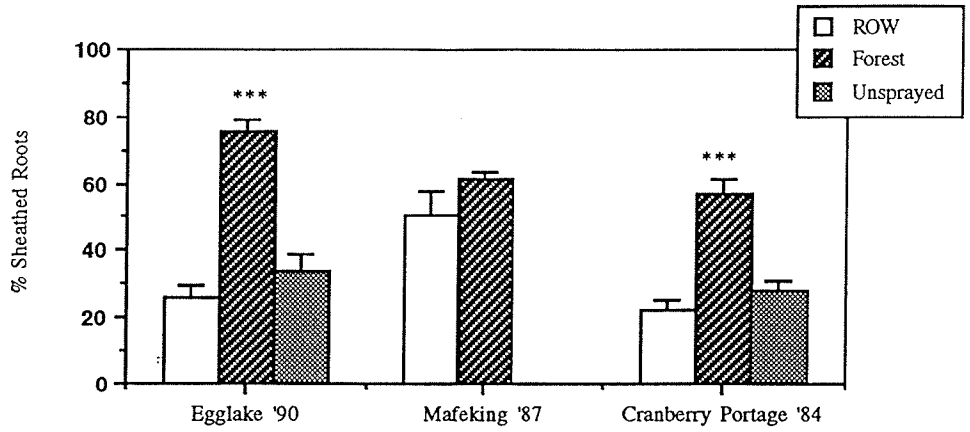
Egg Lake

A total of nine mycorrhizae are found in the Egg Lake site collections (Table 4.1). The spruce ROW and forest collections are high in percent infestation of White Mycorrhiza, together with *Cenococcum*, Soft White, Brown and Beige Mycorrhizas (Figure 4.2). The forest is particularly dense in Angel-White mycorrhiza and *Piloderma croceum.* Spruce roots within the unsprayed Egg Lake ROW are uniquely infested by Grey Mycorrhiza.

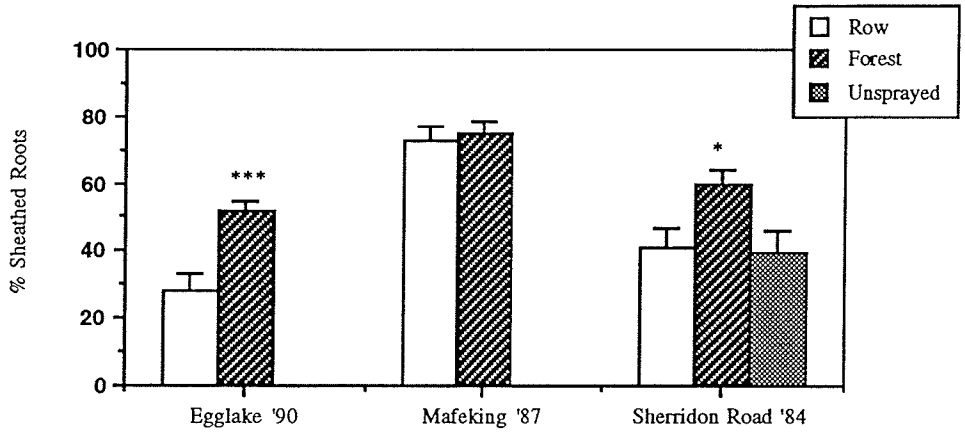
Figure 4.1:

Mean percent mycorrhizal infestation of target tree saplings in the ROW and forest of Spruce, *Picea mariana* (Mill.) B.S.P. dominated, Jack Pine, *Pinus banksiana* Lamb. dominated, and Tamarack, *Larix laricina* (Du Roi) Koch dominated sites. (Means are based on the percent infestation of ten seedling root system.) The year of the last herbicide treatment at the site is indicated along the horizontal axis. Significance levels are indicated above the histogram bars (***: $p \leq .001$; **: $p \leq .01$; *: $p \leq .05$).

a) **Spruce Research Sites**



b) **Jack Pine Research Sites**



c) **Tamarack Research Sites**

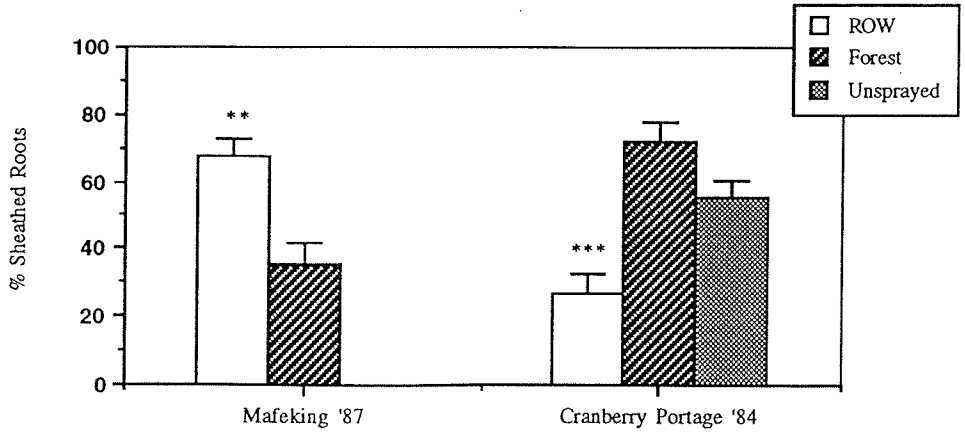


Table 4.1: Mycorrhizal types found at each ROW, forest and unsprayed research site associated with spruce, jack pine and tamarack. Percent seedlings colonized by each mycobiont and total number of species found per site is indicated. Percent Presence (%P) is calculated as the number of sites of occurence of a given symbiont divided by the total number of sites and expressed as a percentage.

Mycorrhizae		Research Sites*																			
	%P	CSR	CSF	CSU	CTR	CTU	MPF	MPR	MSR	ESR	EPF	EPR	MTF	MTR	ESU	SPR	ESF	SPU	CTF	SPF	MSF
Cenococcum sp.	100	100	100	100	70	100	100	100	100	60	100	100	100	100	100	90	100	100	100	100	100
White	100	100	90	100	90	90	40	40	70	40	70	90	100	100	70	100	100	40	100	40	80
Soft White	65	20	40	50	30	10			10	10		20				50	10		10	80	20
Brown	60				30	10			40	40			40	50	30	80		70	60	20	40
Beige	45						20		20	10	40	10		20			50	20			30
White-yellow	25						30	10			10		10		30						
Piloderma sp.	20										40	10					50	20			
Angel White	20												10				40			10	30
Grey	20							10						10	30			10			
Clear	15															10			20		10
Bright White	5																		20		
Pink	5																			10	
No. Species	12	3	3	3	4	4	4	4	5	5	5	5	5	5	5	5	6	6	6	6	7

*Site codes are: C=Cranberry Portage; S=Sherridon Road; M=Mafeking; E=Egg Lake; Tree species: S=Spruce; T=Tamarack; P=Pine; Collection site: R=ROW; U=Unsprayed ROW; F=Forest.

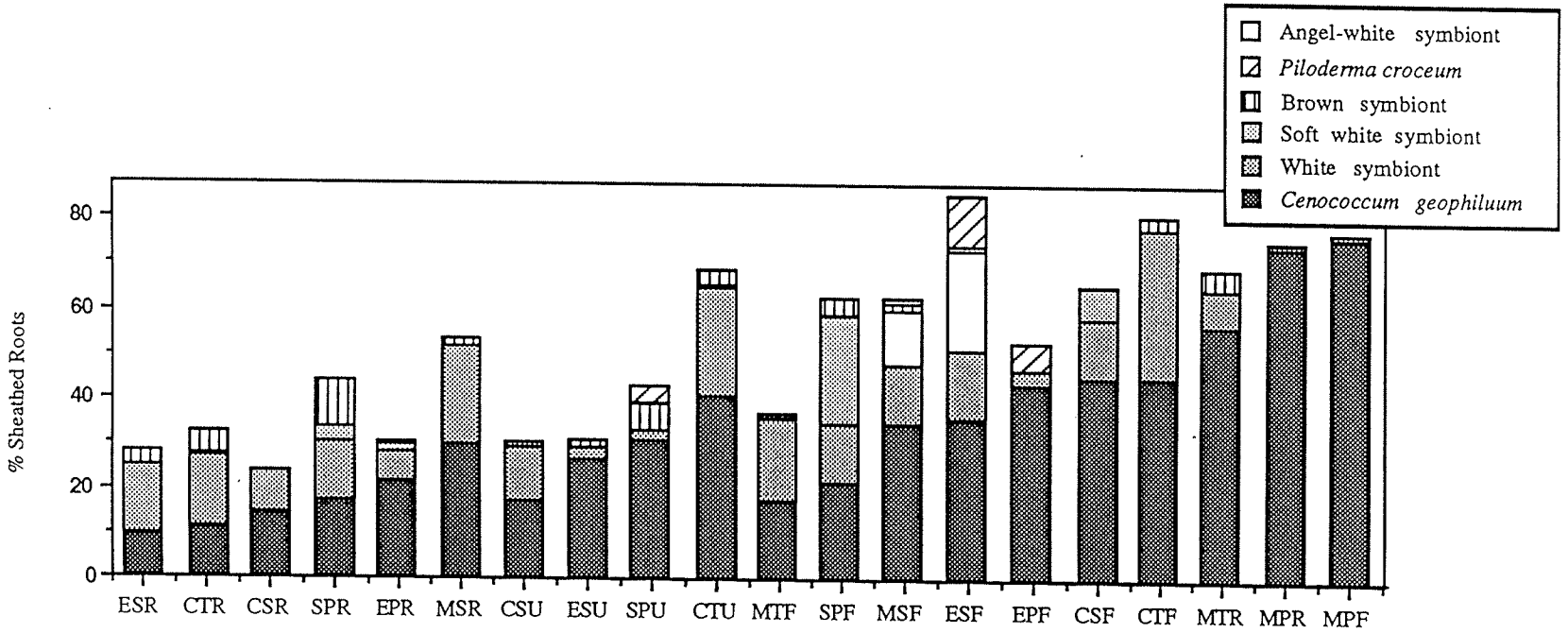


Figure 4.2: Mean percent sheathed roots of individual symbionts at each site. Sites are arranged by treatment (ROW, Unsprayed ROW or forest) and in increasing order of percent infestation with *Cenococcum geophilum.*

Mafeking

A total of nine mycorrhizae are present on roots from the Mafeking sites. Mycorrhizal collections from pine roots are almost entirely *Cenococcum geophilum*, but also include White and White-Yellow Mycorrhizae. Grey Mycorrhiza is found only from the ROW collections, while Beige Mycorrhiza is collected from the forest. Spruce roots are largely colonized by *Cenococcum*. White, Soft-White, Brown and Beige mycorrhizae are found within the ROW collections together with Angel-White and Clear mycorrhizae within the forest. Tamarack roots are largely colonized by *Cenococcum* in the ROW. The forest root collections are primarily infested by White Mycorrhiza and *Cenococcum*, with lower levels of Angel-White and Beige mycorrhizae.

Cranberry Portage

A total of six symbionts are collected from the Cranberry Portage bog sites. Spruce roots are infested by three mycorrhizal types: *Cenococcum*, White Mycorrhiza and Soft-White Mycorrhiza. Tamarack seedlings in the ROW, forest and unsprayed ROW are colonized by *Cenococcum*, White Mycorrhiza and Brown Mycorrhiza. In addition, tamarack forest root collections are infested at low levels with Clear and Bright-White mycorrhizae.

Sherridon Road

A total of nine symbionts are encountered in the Sherridon Road pine site. Seedling roots from the ROW and forest are relatively low in percent infestation by *Cenococcum*. These collections are dominated by White, Brown and Soft-White mycorrhizae. The forest collections also include the rare appearance of a Pink Mycorrhiza. Collections of pine roots from the unsprayed site are predominantly infested by *Cenococcum*, *Piloderma*, White Mycorrhiza and Brown Mycorrhiza. Roots from this site also show low levels of Beige and Grey mycorrhizae.

Mycorrhizae : Presence, Frequency and Infestation Levels

In the following descriptions each mycorrhiza is delimited by it's distribution within and among the sites and percent infestation of roots. Percent presence is calculated as the number of collections in which a species is found divided by the total number of collections (20). The frequency of a mycorrhizal species at a site is calculated as the number of seedlings colonized divided by the total number of seedlings. A short paragraph describes the mean infestation of each mycorrhizal symbiont in the forest, sprayed ROW and Unsprayed ROW of each site, together with the overall means for each treatment. Sites exceptionally high or low in infestation are highlighted in the text. Symbionts having mean infestation levels below 3% at each site are described only in terms of percent presence and percent seedlings colonized and are considered uncommon.

Cenococcum geophilum

Cenococcum geophilum is present at all the research sites (Percent presence, P = 100%) (Table 4.1). Generally, between 90 to 100% of the seedlings at a site are colonized by symbiont, irrespective of tree species. The ESR site, sprayed in 1990, has only 60% of seedlings colonized, a lower percentage than at any other site.

Percent root tips sheathed by *Cenococcum geophilum* vary between the ROW and adjacent forest of each site and among sites (Figure 4.2). Forest levels range between 19.8 ± 6.3% (SPF) to 72.8 ± 4.2% (MPF) with a mean of 38%. ROW levels vary between 8.6 ± 1.1% (ESR) to 70.4 ± 5.0% (MPR) with a mean of 28%. Unsprayed ROW levels range between 16.0 ± 2.8% (CSU) and 37.8 ± 7.8% (CTU) with a mean of 27%. Generally, over 50% of sheathed roots on each tree's root system are attributed to this species. Exceptions are at the Mafeking pine sites were over 95% of the roots are sheathed by this symbiont and at ESR, SPF and CTR where *Cenococcum* is reduced to only a third of the mycorrhizae which appear dominated by White and Brown mycorrhizae. ROW sites in general tend to be lower in *Cenococcum* than forest and unsprayed ROW sites, and cluster to the left of Figure 4.2, while the forest and Mafeking sites cluster to the right.

White Mycorrhiza

The White Mycorrhiza is present in 100% of the sites. The percentage of seedlings colonized by this mycorrhizae at each site is much less consistent than is the case with *Cenococcum.* Generally, between 70 to 100% of the seedlings are colonized. Root collections low in mycorrhizal infestation frequency include spruce at ESR and jack pine at MPR, MPF, SPF and SPU.

Forest levels of unidentified white mycorrhizae range between 1.0 ± 0.5% (MPF) to 30.6 ± 5.4% (CTF) with a mean of 14.6%. ROW levels range between 1.0 ± 0.5% (MPR) to 20.9 ± 5.2% (MSR) with a mean of 10.9%. Unsprayed sites are similar to the ROW in levels of this mycorrhizae ranging from 2.2 ± 1.0% (SPU) to 22.9 ± 5.5% (CTU) with a mean of 9.7%. Sites exceptionally high in this mycorrhiza include CTF, CTU, CTR, MSR and MTF. Sites low in this mycorrhiza include MPR, MPF, and SPU.

Soft White Mycorrhiza

Soft-White Mycorrhiza is present in 65% of the collection sites. This mycorrhiza is found over a range of frequencies (ie. 10% at MSR, ESR, ESF and CTF and 80% at SPF).

Forest levels range from 0.4 ± 0.4% (CTF) to 22.4 ± 8.2% (SPF), with a mean of 6.3%. ROW sites range from 0.2 ± 0.2% (CSR) to 1.6 ± 1.1% (EPR) with a mean of 1.0%. Infestations in unsprayed sites vary between 0.2 ± 0.2% (CTU) and 1.4 ± 0.6% (CSU) with a mean of 0.8%. Sites notably high in this mycorrhiza include SPF and CSF.

Brown Mycorrhiza

Present in 60% of the sites, this symbiont is most evident in collections from SPR, SPU and CTF, as 60 to 80% of the seedlings are colonized. Brown Mycorrhiza is associated with 40 to 50% of spruce and tamarack at Mafeking and 30 to 40% of spurce at ESF and ESU.

Forest tree root infestation levels by this mycorrhiza range between 0.5 ± 0.3% (MTF) and 3.8 ± 2.6% (SPF) with a mean infestation of 2.3%. Infestation levels in ROW collections range between 1.6 ± 0.7% (MSR) and 9.6 ± 4.5% (SPR) with a mean for all sites of 4.6%. In unsprayed sites mycorrhizal infestations range between 1.4 ± 0.6% (ESU) and 5.6 ± 2.0% (SPU) with a mean of 3.4%. Sites exceptionally high in this symbiont include CTR and SPR.

Piloderma croceum

Piloderma croceum is present in 20% of the research sites. This mycorrhiza is found at ESF infesting 50% of the seedlings. Infestations in EPR and EPF collections are 10 and 40%, respectively. *P. croceum* mycorrhizae are observed on 20% of seedlings from SPU. This symbiont was never observed in association with tamarack roots.

The mean percent root tips colonized by *Piloderma croceum* range between 3.8 ± 3.6% (SPU) and 10.6 ± 4.6% (ESF). Trace levels of infested tips also appear in EPR collections.

Angel White Mycorrhiza

Present at 20% of the sites, this symbiont is most prevalent at ESF where it forms mycorrhizae with 40% of seedlings, and MSF where it is found with 30% frequency. Two additional sites, MTF and SPF, show 10% seedling colonization.

Angel-White Mycorrhiza appears at high infestation levels at two sites, reaching 11.3 ± 5.9% (MSF) and 20.6 ± 8.8% (ESF).

Uncommon Mycorrhizas

Other symbionts, such as the Beige, White-Yellow, Grey, Clear, Bright-White and Pink mycorrhizas occur at mean infestation levels lower than 3% at each site. Beige mycorrhizae is found at 45% of the sites. Colonization levels are generally below 20%. Egg Lake jack pine and spruce seedlings have the highest frequency of this symbiont, reaching 40

and 50% of trees, respectively. Yellow-White Mycorrhiza, appearing in 25% of the sites, is found in association with 30% of trees at MPF and ESU, and 10% of trees at MPR, EPF and MTF. Grey Mycorrhiza occurs at 20% of the sites associated with roots of all three target species. It is found in the unsprayed ROW sites of ESU and SPU at 30 and 10% frequency, respectively, and at MPR and MTR at 10%. Clear Mycorrhiza is found with 10% of spruce at MSF, 10% of jack pine at SPR and 20% of tamarack at CTF and it appears in 15% of the sites. Bright-White Mycorrhiza is present in 5% of the sites studied and it is associated with 20% of tamarack seedlings at CTF. Finally, Pink Mycorrhiza is present at 5% of the sites and is found associated with 10% of jack pine seedlings at SPF.

Multivariate Results

Principle Components Analysis (PCA) ordinating mean mycorrhizal levels against percent infestation by total sheathed roots, *Cenococcum* and White Mycorrhizae (Figure 4.3) reveals a clear ROW/Forest separation in the data. The horizontal axis (Axis 1) represents 60.0% of the cumulative variance and the verticl axis (Axis 2) represents an additional 36.5% of the variance. The observed separation along Axis 1 may be related to tree density and possibly soil nutrient factors, while separation along Axis 2 appears to be related to soil moisture. Forest sites fall on the right side of Axis 1. High in total sheathed roots and predominantly colonized by *Cenococcum*, MPF, MPR, EPF and MTR are separated along Axis 2 and appear together in the bottom right quadrant. Sites high in white mycorrhizae such as MSF, CSF, ESF, CTU and CTF, are found in the top right quadrant. Sites high in percent infestation of white mycorrhizae are generally high in percent water. (See Chapter I of this thesis for more information on site soil attributes.) Two outlying ROW sites, MPR and MTR, fall in with the forest stands. Most ROW and Unsprayed ROW sites fall to the left of Axis 1.

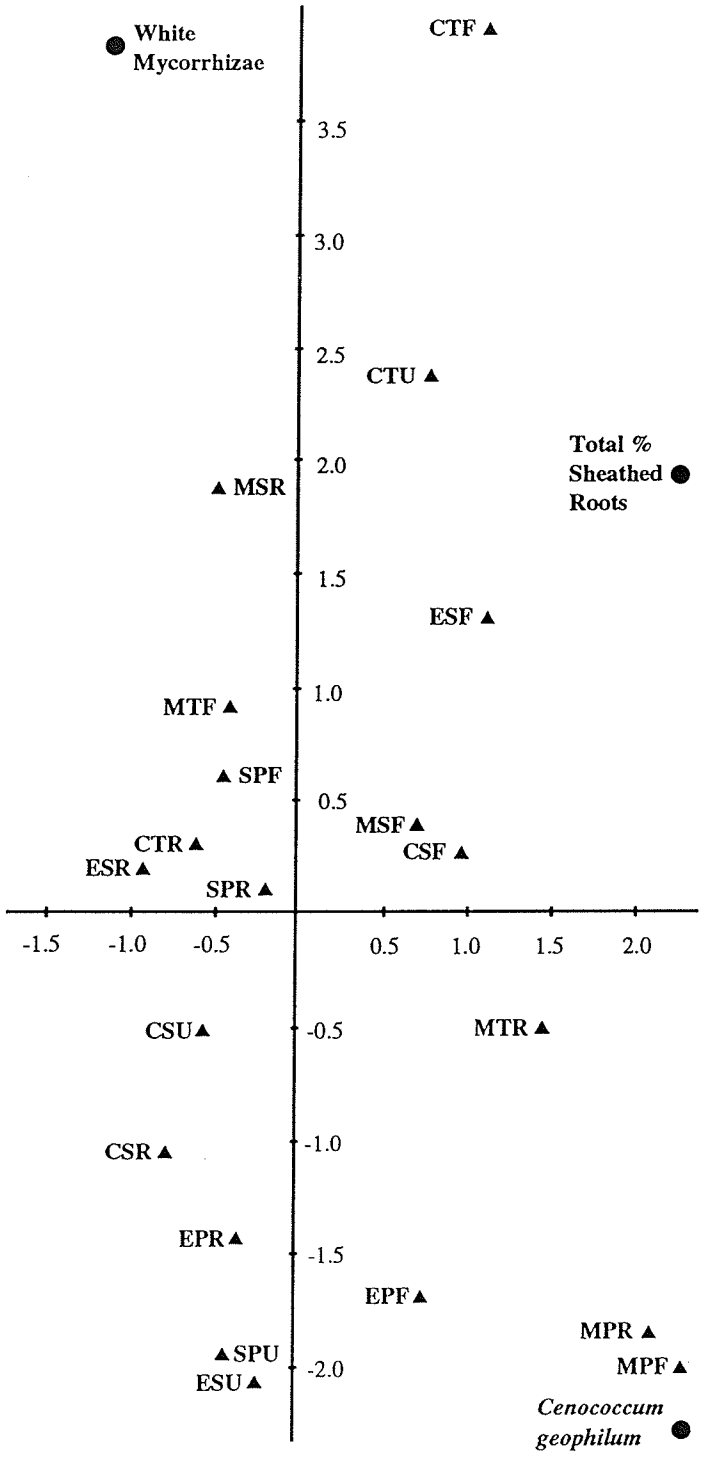
Figure 4.3:
Scatter diagram of mycorrhizal attributes of 20 root collections based on total percent sheathed roots and infestation with *Cenococcum geophilum* and an unidentified white mycorrhiza. The horizonal axis, possibly related to tree density and soil nutrient factors, separates sites according to mycorrhizal infestation intensity. Forest sites, being high in percent sheathed roots, fall to the right, while sites low in infestation fall to the left. The verticle axis corresponds to a soil moisture and pH gradient. Wet sites, being high in percent infestation of white mycorrhizae are found above, while pine sites, generally dry, tend to cluster below.

Site collections, indicated as solid triangles (▲), are:

EPR and EPF = Egg Lake Pine ROW and Forest
ESR, ESU and ESF = Egg Lake Spruce ROW, Unsprayed ROW and Forest
MSR and MSF = Mafeking Spruce ROW and Forest
MTR and MTF = Mafeking Tamarack ROW and Forest
MPR and MPF = Mafeking Pine ROW and Forest
CSR, CSU and CSF = Cranberry Portage Spruce ROW, Unsprayed ROW and Forest
CTR, CTU and CTF = Cranberry Portage Tamarack ROW, Unsprayed ROW and Forest
SPR, SPU and SPF = Sherridon Road Pine ROW, Unsprayed ROW and Forest

Mycorrhizal attributes, indicated as solid circles (●), are:

Total % Sheathed Roots
Cenococcum geophilum
White Mycorrhiza


White Mycorrhizae
CTF ▲
3.5
3.0
2.5
CTU ▲
Total % Sheathed Roots
2.0
▲ MSR
1.5
ESF ▲
1.0
MTF ▲
▲ SPF
0.5
MSF ▲
CTR ▲
CSF ▲
ESR ▲
SPR ▲
-1.5
-1.0
-0.5
0.5
1.0
1.5
2.0
CSU ▲
-0.5
MTR ▲
CSR ▲
-1.0
EPR ▲
-1.5
EPF ▲
MPR ▲
▲ SPU
MPF ▲
ESU ▲
-2.0
Cenococcum geophilum

DISCUSSION

ROW : Forest Differences

The data show that mycorrhizae are suppressed within the ROW compared to the adjacent forest of most sites, irrespective of tree species and the date of herbicide application at the site (Figure 4.1). Per tree there is generally 20 to 50% fewer mycorrhizal roots on trees within the disturbed sites, whether they be sprayed or unsprayed. Other studies also report lower levels of mycorrhizae within disturbed sites (Vare 1989; Perry et al. 1987). On the question of site and herbicide application date, in my study they appear to be confounding variables.

Mafeking ROW Outliers

The Mafeking (1987) ROW sites are notably higher in mycorrhizal infestation than those in other ROW sites. Levels of infestation within the ROW generally fall below 30% and never exceeded 40% but the Mafeking sites show above 60% infestation on both jack pine and tamarack roots, and above 50% on spruce roots. These unusually high levels of infestation may be due to regional differences in soil and climatic regimes or they may be due to the use of the herbicide *Tordon 10K* rather than *Tordon 101* (Appendix I). At Mafeking, a warmer, more southern collection site, climatic differences can not in themselves explain the dramatic mycorrhizal findings. However, *Tordon 10K*, a pellet formulation of *Picloram* without the 2,4-D component, may be enhancing mycorrhizal levels by acting as a nutrient source in an otherwise closed system. If *Picloram* is having a stimulatory effect on mycorrhizae, it may explain its frequent and successful use for reforestation with coniferous tree species (Neary et al.. 1985; Neary et al. 1984). This effect is contrary to efficient ROW management.

Root collections from the Mafeking sites were also anomalous in their almost exclusive colonization by *Cenococcum geophilum.* Fires at these sites over the past century may have conferred competitive advantage to this fungus. Jack pine roots are over 95%

colonized by *Cenococcum* at this site. As Jack pine relies on fire for seed release, this tree's association with a fire-resistant fungus is not accidental.

Herbicide Effects

Time since spraying may have definite short and long term effects on fungal populations (Wardle and Parkinson 1991). However, site variability makes comparison of different spray times within this study very difficult. Wardle and Parkinson (1991) agree that variation within the environment makes for a background of spatial and temporal 'noise', which obscures revealing herbicide side-effects. Generalization about how management appears to effect mycorrhizal fungi in Hydro ROW's is, however, possible. Management techniques employing use of *Tordon 10K* seems to have a positive effect on mycorrhizal populations, and definitely exerts no overall negative effect on these fungi. This result is consistent for all three target species examined at the Mafeking sites. The more persistent *Picloram* component of the herbicide formulation may be suppressing certain symbionts, while enhancing the success of others.

Chemical and physical sources of disturbance, may have effects on soil microflora. However, toxic effects of *Tordon* formulations to the fungal community, if present, are most likely transient and visible only within a short time after spraying (Wardle and Parkinson 1989). Indirect effects due to the loss of host trees and their protective canopy, increased light and decreased moisture, are most likely the important factors in reducing colonization levels.

Unsprayed Sites

The depressed levels of mycorrhizae observed in three of four unsprayed ROW root collections compared to their neighboring forest collections indicate that some factor other than herbicides are causing the reductions in mycorrhizae commonly found within the ROW. Soil compaction from initial line clearance and additional habitat changes after loss of the forest canopy may be causing the observed depressed levels of infestation. Low and excessively

high soil moisture has been shown to suppress root infestation by ectomycorrhizae (Ietswaart et al. 1992; Coutts and Nicoll 1990; Brundrett and Kendrick 1988; Douds and Chaney 1986; Fogel 1980; Rabatin 1979). Seasonal changes in soil moisture may explain the reduced levels of mycorrhizae associated with tree roots from unsprayed sites. Reduced soil moisture retention within the more open, sprayed ROW environment may cause the even more pronounced reductions in mycorrhizal levels found at most sites.

Mycorrhizal Species

The dominance of *Cenococcum geophilum* at all collection sites is not unexpected. High *Cenococcum* infestation levels are reported in other mycorrhizal studies of this forest type (Massiotte et al. 1992; Erland and Soderstrom 1991; Shaw and Sidle 1983; Christy et al. 1982). The White Mycorrhiza, forming smooth pinnate mycorrhizae at all sites, is possibly related to mushrooms of the genera *Cortinarius* and *Suillus*.

Piloderma croceum Erikss. & Hjorts is restricted by pH and soil moisture requirements, and hence is limited in its competition with many fungi, especially *Cenococcum* spp. (Erland and Soderstrom 1991). It's presence at only a handful of the bog sites in association with spruce, and pine at the Sherridon Road unsprayed site is, thus, not unexpected.

The other ten symbionts observed in the study, which occur at low levels of infestation and variable frequencies at the sites, are similar in characteristics to other forest mycorrhizas (Dahlberg and Stenstrom 1991; Danielson 1984; Danielson and Visser 1989; Shaw and Sidle 1983; Christy et al. 1982; Danielson and Pruden 1989; Harvey et al. 1976; Malloch and Malloch 1982; Doudrick et al. 1990; Malloch and Malloch 1981; Brundrett et al. 1990). For example, an unidentified pink mycorrhizae, tentatively named *Pinirhiza rosea* Uhl (Uhl 1988), has been noted by two authors (i.e. Erland and Soderstrom 1991 and Erland and Findlay 1992). The characteristics of the Pink Mycorrhiza in this study are quite similar to descriptions given by these authors.

Site Species Richness

Species richness, measured as the number of symbionts per site, ranges between three to seven symbionts. Forest and unsprayed areas are generally more diverse than sprayed ROW sites. This finding corresponds to similar studies comparing mycorrhizae between mature forest stands and clear-cut areas (Perry et al. 1987; Pilz and Perry 1984). More favorable moisture conditions in the forest, or possibly the greater abundance of soil organic matter may explain this tendency. In this study, the bog sites at Cranberry Portage are the lowest in mycorrhizal diversity. This finding corresponds to other studies of mycorrhizae in bog plant communities (Dahlberg and Stenstrom 1991; Doudrick et al. 1990).

Woody Plant Diversity and Tree Density and Mycorrhizae

Woody plant diversity and tree density do not seem to be related to mycorrhizal levels within the sprayed ROW. ROW sites which are high in tree density and woody diversity do not necessarily exhibit higher levels of mycorrhizal infestation. For example, the Cranberry Portage spruce ROW, which is high in spruce density and the tamarack ROW, which is high in woody diversity, are average in the percent mycorrhizal colonization of roots. The Mafeking sites, which are intermediate in tree density, are high in percent mycorrhizal roots.

CHAPTER CONCLUSIONS

There is a marked dichotomy between ROW and forest levels of mycorrhizal infestation at most sites with all three target tree species examined. The suppression of mycorrhizae within the ROW is likely due to a combination of factors including: the decreased density of host tree roots for colonization, soil compaction from original line clearance, and abiotic factors such as increased light and exposure to the elements.

Cenococcum geophilum, Piloderma croceum, Cortinarius sp. and several unidentified mycorrhizas show a broad distribution throughout the boreal forest, appearing at several sites. These fungal species are often associated with ericaceous shrubs common to the boreal forest.

CHAPTER V

CHANGES IN MYCORRHIZAE OF BLACK SPRUCE (*PICEA MARIANA* (Mill.) B.S.P.) AFTER GROUND APPLICATION OF *TORDON 101* AT A PEAT BOG SITE AT WATERHEN, MANITOBA

INTRODUCTION

Many herbicides have been found to eliminate essential mycobionts in forestry and horticultural plantations (Nemec and Tucker, 1983; Trappe et al., 1984; Chakravarty and Chatarpaul, 1990; Chakravarty and Chatarpaul, 1988; Marx et al., 1978; Trappe, 1983; Kelly and South, 1980). Because fungal survival has an impact on plant survival and vise versa, inoculum potential of mycorrhizae and changes of the potential after herbicide treatment can be critical in directing plant succession (Hepper et al. 1988; Perry et al.1989; Allan and Allan, 1984). A surge in ectomycorrhizal activity after herbicide application may aid in tree survival and new seedling establishment at a site. Conversely, a diminishing of fungal viability due to chemical toxicity may hinder tree success. In this way, management of mycorrhizae can be used to influence development of tree stands or shrub thickets depending upon the density and the affect of herbicides on specific mycobionts.

In this study, the effects of picloram on the type and intensity of mycorrhizae associated with black spruce, *Picea mariana* (Mill.) B.S.P. are assessed. The non-target effects of Picloram formulations on mycorrhizal fungi have not yet been tested in the field. So as to provide information on picloram's affect, this study looks at mycorrhizae associated with *Picea mariana* just after herbicide treatment and subsequently. Factors which influence the level of infestation, such as the season of sampling, photo-period, climatic conditions, soil type, pH, moisture and land use, may be controlled for by examining concommittant changes in mycorrhizae in the undisturbed adjacent forest (Coutts and Nicoll 1990a, b; Fogel and Hunt 1983; Rabatin 1979; Saif and Khan 1975).

MATERIALS AND METHODS

Description of the study site

A peat bog located at 52°37'N, 100°25' E, near the town of Waterhen, Manitoba, was chosen for studying the effects of *Tordon 101* herbicide formulations on mycorrhizal fungi associated with *Picea mariana.* This site was chosen for target tree presence within the ROW, as well as projected herbicide application date and *Picloram* formulation being used.

The dominant vegetation at the site is *Picea mariana,* occurring at very high densities (Figure 5.1), with a dense ericaceous shrub understory and sporadic cover of willow and poplar species (Figure 5.2). The dominant soil type is organic cryosolic soils on fibric sphagnum. The soil is a poorly drained peat with the water table 0 - 2m below ground. Soil parent material is organic and its origin is from mesic woody forest. The area is morainal ridged with a slope of 1 - 3%. Extensive fires in 1958, 1961 and 1964 have burned this site.

Line G31V, the corridor of this study, was cleared in 1974 and sprayed in 1976 with a formulation of 2,4-D and 2,4,5-T. No subsequent vegetation management occurred at the site until July 1991, a day prior to the first root collections.

Experimental Design and Vegetation Sampling

Five belt transects each 23m across the ROW by 2m wide were sampled for seedling root systems. Number and height of all target trees and non-target shrubs were recorded per meter within each transect. Woody vegetation of the forest was sampled for presence or absence of species at 5m intervals along ten 50m line belts set up adjacent to the ROW for a total of 100 half meter square plots.

Figure 5.1.
Waterhen Spruce ROW site (WSR Tower 316). Line G31V. Site vegetation is dominated by young spruce trees growing in a dense bed of ericoid shrubs and *Sphagnum* moss. The low height of adjacent forest trees indicate recent fire coupled with a slow regrowth rate often found at nutrient poor bogs. The ROW Tower shown is supporting an eagle nest (July 1991).


5.1

Figure 5.2.
Waterhen Spruce ROW transect showing understory layer of labrador tea, *Ledum groenlandicum*. Other common woody species visible within the transect include willow and poplar. Site treatment with *Tordon 101* occurred one day prior to root sampling. Apical elongation and epinasty of tamarack can be seen in the foreground (July 1991).


5.2

Mycological Sampling and Identification

Thirty *Picea mariana* seedlings were collected randomly from the ROW transects for mycorrhizal sampling on July 20, 1991. Twenty seedlings were collected two months after site treatment (September 4, 1991) and again ten months after treatment (May 18, 1992). Fifteen seedlings were collected as controls at each sampling time from the adjacent undisturbed forest. Feeder roots and mycorrhizae of the collected seedlings were carefully extracted from the organic soil layers (Dighton 1991 and Harvey et al. 1976).

All roots were washed with tap water and fixed in 50% ethanol (Koske and Gemma 1989) before examination for mycorrhizae. Feeder roots, placed in petri dishes, were examined microscopically to characterize mycorrhizae. Fifty root tips were scored per root system using a line/intersect grid. Hartig net formation by the mycotrophs was confirmed using 2μm cross sections of root tips stained with Chlorozol Black E and observed under 40x to 100x light microscope magnification. Details of mycorrhizae identified are outlined in Chapter III of this thesis.

ROW and forest areas were surveyed for fungal sporocarps in late September as a means of identifying mycotrophs.

Soil Analysis

Soil samples taken from within the ROW and forest were analysed according to standard procedures for determination of pH, conductivity, bulk density, organic content, soil moisture and soil water holding capacity. Methods and procedures of analysis are detailed in Chapter II of this thesis.

Data Analysis

ANOVA was used to determine if differences were significant between the ROW and Forest collections and between the collection dates for each treatment ($p \leq .05$). Tukey Box-plots (Figure 5.3) were used to present the variation in the data within the sites and transects.

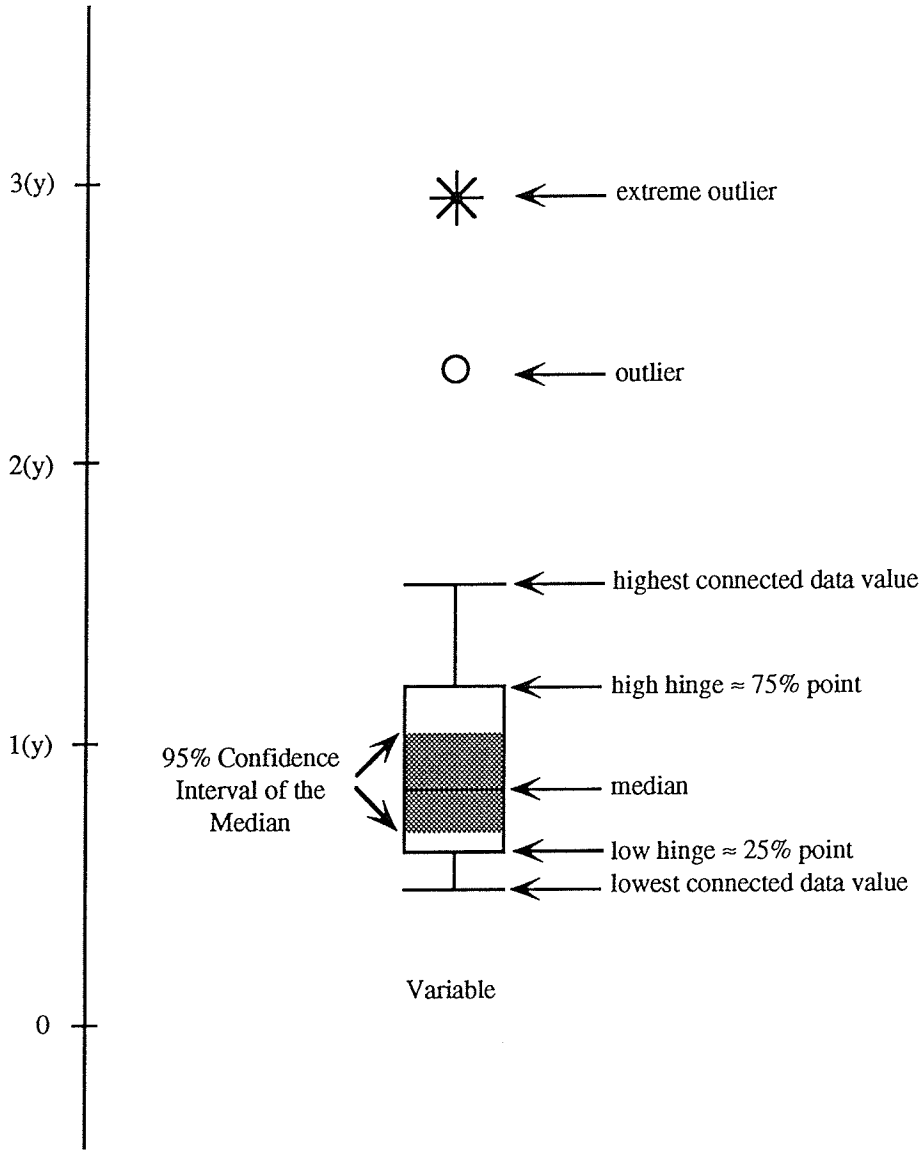


Figure 5.3: Diagram of a Boxplot showing the median with it's 95% confidence interval, the ± 1.0 interquartile range (25% point to 75% point) represented by the rectangular box and the ± 1.5 interquartile range shown by the limits of the "T". Circles and stars represent outliers within and beyond the ±3.0 interquartiles, respectively. (from Velleman 1988).

The Shannon and Weiner (1963) Index for calculating species diversity, expressed as:

$$H' = - \sum Ni/N \log Ni/N$$

where N is the number of individuals recorded and Ni is the number of individuals of the 'ith' species, was used to estimate plant and mushroom diversity within transects for comparison with transect mycorrhizal findings. This index considers both species richness (numbers of species) and evenness (numbers of individuals per species).

RESULTS

Changes in Mycorrhizal Infestation Over Time

Mycorrhizal infestation of *Picea mariana* seedlings in both the ROW and forest changed between July 1991 and May 1992 (Figure 5.3a, b). Mean mycorrhizal levels within the ROW in July 1991 were 27.3 ± 2.7% (n = 30) (Table 5.1a). The mean percentage of fully sheathed roots of forest seedlings in July 1991 was 42.5 ± 4.1% (n = 15) which is 15.3% higher than ROW levels ($p \leq .01$). (Analysis of variance results are shown in Table 5.1b.) In September 1991, ROW levels of mycorrhizae had not significantly changed from July 1991 levels at 24.4 ± 2.7%. Conversely, forest levels had dropped by 20% ($p \leq .05$) between July 1991 and September 1991 reaching 22.9 ± 2.8%. In May 1992, ROW mycorrhizae increased by approximately 20% compared to September 1991 levels, reaching 46.6 ± 4.2% ($p \leq .001$). Forest levels reached a mean of 53.6 ± 6.0% in May 1992, a significant increase ($p \leq .001$) of 30% between September 1991 and May 1992. Levels between the ROW and forest were not significantly different in May 1992. There are no significant differences between July 1991 and May 1992 forest collections, however, the May 1992 ROW levels of infestation were increased dramatically over the July 1991 levels ($p \leq .001$).

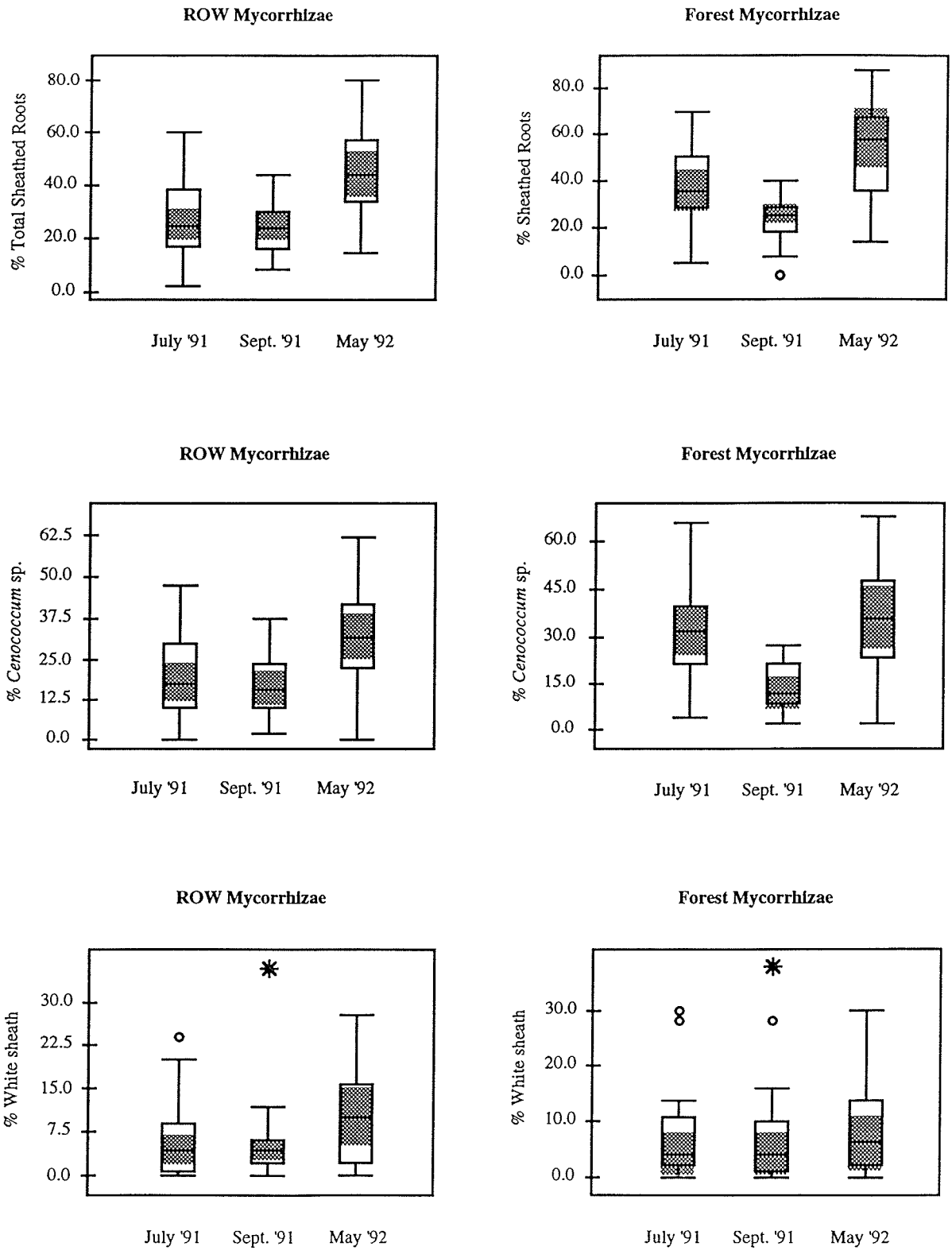


Figure 5.4. Percent sheathed roots and infestation of Waterhen ROW and forest *Picea mariana* seedling roots with *Cenococcum geophilum* and White Mycorrhiza.

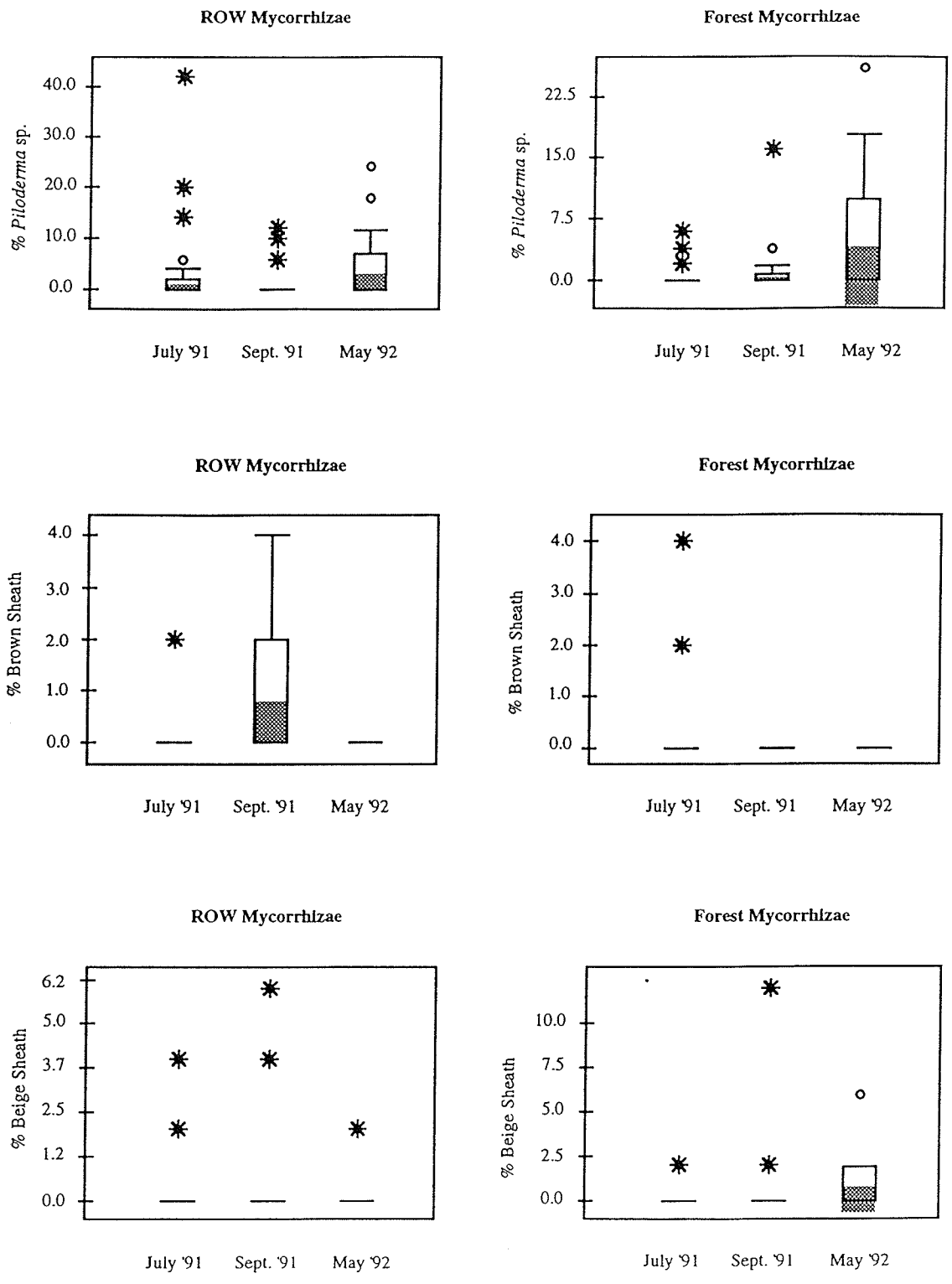


Figure 5.5: Percent sheathed roots and infestation of Waterhen ROW and forest *Picea mariana* seedling roots with *Piloderma croceum*, Brown Mycorrhiza and Beige Mycorrhiza.

Table 5.1a: Mean percent (± S.E.) sheathed roots and percent infestation with the five most frequent mycobionts associated with ROW and forest *Picea mariana* seedling roots at Waterhen.(N = 30 for the July 1991 ROW; N = 20 for the September 1991 and May 1992 ROW collections and N = 15 for all forest collections.)

Collection Site	July 1991*		September 1991		May 1992	
	ROW	Forest	ROW	Forest	ROW	Forest
% Sheathed roots	27.27 ± 2.72	42.57 ± 4.06	24.35 ± 2.69	22.93 ± 2.80	46.63 ± 4.19	53.60 ± 6.02
Cenococcum sp.	18.07 ± 2.38	31.14 ± 3.73	17.41 ± 2.53	12.53 ± 2.33	32.00 ± 3.94	33.47 ± 5.18
White Mycorrhiza	6.07 ± 1.20	8.29 ± 2.62	5.53 ± 2.05	8.13 ± 2.90	10.53 ± 2.01	9.87 ± 2.32
Piloderma sp.	3.20 ± 1.57	0.86 ± 0.50	2.35 ± 1.10	1.60 ± 1.07	4.74 ± 1.77	4.40 ± 2.18
Brown Mycorrhiza	0.13 ± 0.09	1.86 ± 1.43	0.82 ± 0.35	-	-	3.20 ± 2.68
Beige Mycorrhiza	0.27 ± 0.16	0.29 ± 0.19	0.59 ± 0.41	0.93 ± 0.80	0.11 ± 0.11	1.07 ± 0.43

Table 5.1b: ANOVA results for comparison of mycorrhizal infestations of *Picea mariana* seedling roots between the ROW and forest and between the different collection dates at the Waterhen 1991 spray site. (ROW July, N = 30; ROW Sept, N = 20; ROW May, N = 20; FOREST, all collections, N = 15.) (NS = Not Significant at a 95% confidence interval.)

Mycorrhizal Infestations	ROW and Forest Compared			Collection Dates Compared					
Compared between Sites and Collection Dates	July 1991	Sept. 1991	May 1992	July 91: Sept. 91		Sept. 91: May 92		July 91: May 92	
				ROW	Forest	ROW	Forest	ROW	Forest
% Sheathed Roots	0.01	NS	NS	NS	0.01	0.001	0.001	0.001	NS
Cenoccocum geophillum	0.01	NS	NS	NS	0.01	0.01	0.01	0.01	NS
White Mycorrhiza	NS	NS	NS	NS	NS	NS	NS	NS	NS
Piloderma croceum	NS	NS	NS	NS	NS	NS	NS	NS	NS
Brown Mycorrhiza	NS	NS	NS	0.05	NS	0.05	NS	NS	NS
Beige Mycorrhiza	NS	NS	0.05	NS	NS	NS	NS	NS	NS

Percent infestation by the individual mycobionts generally reflects the overall fluctuations in mycorrhizae over the study period. *Cenoccocum geophilum* Fr. is the most frequent mycobiont within the ROW and forest (Figs. 5.3c,d). Mean *Cenococcum* levels within the ROW range from 18.1 ± 2.7% in July 1991, to 17.4 ± 2.5% in September 1991 (NS) and to 32.0 ± 3.9% in May 1992 ($p \leq .001$). Forest levels change from 31.1 ± 3.7% in July 1991, to 12.5 ± 2.3% in September 1991 ($p \leq .001$) to 33.5 ± 5.2% in May 1992 ($p \leq .001$). ROW infestation levels in July 1991 are significantly lower than forest levels at this time ($p \leq .01$)(Table 5.2) There is no significant difference in ROW levels of *Cenococcum* between July and September 1991 or between the ROW and forest collections in September. ROW levels of mycorrhizae are significantly higher in May 1992 than in July and September 1991 ($p \leq .001$). Differences were significant between each consecutive forest sampling, but were not significant between July 1991 and May 1992.

The White Mycorrhiza are a major mycorrhizal component on root tips (Fig. 5.3e, f). Means within the ROW range from 6.1 ± 1.2% in July 1991 to 5.5 ± 2.0% in September 1991 and to 10.5 ± 2.0% in May 1992. Forest means vary from 8.3 ± 2.6% in July 1991 to 8.1 ± 2.9% in September 1991 and to 9.9 ± 2.3% in May 1992. Both the ROW and forest show a slight decline in percent white mycorrhizae in September 1991 and an increase in May 1992, although no differences between site or collection times are significant.

Piloderma croceum Erikss. & Hjorts is present in both the ROW and forest at mean levels generally below 5% (Fig. 5.4a, b). ROW levels of *P. croceum* are consistently higher than forest levels, being 3.2 ± 1.6% in July 1991, 2.4 ± 1.1% in September 1991, and 4.7 ± 1.8% in May 1992. At 0.9 ± 0.5%, levels of this symbiont are almost negligible in the July 1991 forest site. In September 1991, *P. croceum* frequency from forest collections is doubled and infestations are equal to 1.6 ± 1.1%. In May 1992, forest tree infestations of this symbiont quadruple reaching 4.4 ± 2.2%. None of the differences in *P. croceum* infestation levels between sites or sampling times are significant.

Frequencies of Brown Mycorrhiza are lower within the ROW than the forest in July 1991, being 0.1 ± 0.1% from ROW collections compared to 1.9 ± 1.4% from forest trees (Figs. 5.4c, d). ROW levels of infestation with Brown Mycorrhiza are six times higher in September 1991 than in July 1991 reaching 0.9 ± 0.5% ($p \leq .05$). Infestations drop to zero in May 1992 ($p \leq .05$). September 1991 forest levels drop to zero and recover in May 1992 reaching 3.2 ± 2.7%. Changes in forest mycorrhizae are not significant.

The Beige Mycorrhiza is the same in overall mean levels between the ROW and forest in July 1991, being at 0.3 ± 0.2% (Fig. 5.4e, f). Thereafter, infestation levels of Beige Mycorrhiza are greater within the forest than within the ROW being 1.1 ± 0.4% in May 1992 compared to 0.11 ± 0.11% ($p \leq .05$). The occurrence of this symbiont is relatively rare except within the May 1992 forest collection.

Percent Seedlings Colonized

Another useful index for estimating the importance of a mycorrhizal species in an ecosystem is its presence/absence frequency (Percent Frequency) on seedlings, given as the number of seedlings colonized over the total number of seedlings examined. In this study, five mycobionts are common with the infrequent occurrence of eight others (Table 5.2).

Cenococcum geophilum infests virtually all seedlings at each of the collection times, although percent seedlings colonized does vary between 80 to 100%. ROW frequency of *C. geophilum* is 93% in July 1991, and increases to 100% in the September 1991 and May 1992. Forest levels change from 100% in July 1991, to 80% in September 1991, and then rise to 93% in May 1992.

White mycorrhizae within the ROW remains at a constant 80% over the sampling time, while forest levels fluctuate between 80% in July 1991 to 73% in September 1991, and then back up to 87% in May 1992.

Piloderma croceum infestation of seedlings within both the ROW and forest remain relatively constant ranging between 20 to 35%. ROW levels change from 30% in July 1991 to

Table 5.2. Frequency of mycorrhizae (calculated as the number of seedlings colonized divided by the total number seedlings observed) associated with ROW and forest *Picea mariana* seedlings at Waterhen. (N = 30 for the July 1991 ROW; N = 18 for the September 1991 ROW; and N = 20 for the May 1992 ROW. N = 13 for the July 1991 Forest and N = 15 for the September 1991 and May 1992 Forest.)

Collection	July 1991		September 1991		May 1992	
(Seedlings Colonized (%))	ROW	Forest	ROW	Forest	ROW	Forest
Cenococcum geophilum Fr.	93	100	100	80	100	93
White Mycorrhiza	80	80	78	73	80	87
Piloderma croceum (Peck) Julich	30	20	20	31	35	27
Beige Mycorrhiza	10	15	10	7	5	40
Brown Mycorrhiza	3	15	35	7	0	0
White-Yellow Mycorrhiza	0	27	0	7	0	0
Grey Mycorrhiza	7	0	0	0	0	0
White, Angel-Hair Mycorrhiza	0	0	17	13	0	0
Soft-White Mycorrhiza	0	3	0	0	0	0
White-Spongy Mycorrhizae	3	0	0	0	0	0
Bright-White Mycorrhizae	0	0	0	0	3	0

20% in September 1991 and rise to 35% in May 1992. Forest infestation with *P. croceum* changes from 20% in July 1991 to 31% in September 1991 to 27% in May 1992.

The Brown Mycorrhiza within the ROW erratically appears, going from 3% in July 1991, to 35% in September 1991 and altogether disappearing in May 1992. Forest levels of Brown Mycorrhiza vary from 15% in July 1991 to 7% in September 1991, and then also disappear in May 1992. Colonizing only 10% of ROW seedlings in July and September 1991, Beige Mycorrhiza are 5% in May 1992. Forest levels of Beige Mycorrhiza are higher, being 15% in July 1991, 7% in September 1991, and 40% in May 1992. Found only within forest collections the White-yellow mycorrhiza infestations change from 27% in July 1991, to 7% in September 1991, to 0% in May 1992. White, Angel-Hair Mycorrhiza appears only in September 1991 within both the forest and ROW at 13 and 17%, respectively. The remaining unidentified symbionts, described as White-Grey, Soft-White, Spongy-White and Bright-White mycorrhizae, are infrequently observed.

Mycorrhizal Diversity

Similarity between the ROW and forest with respect to the types of mycorrhizae is apparent from the analysis of frequency and diversity of symbionts. Five mycorrhizal types predominate within both the ROW and forest areas, with the sporadic occurrence of six others. The forest contains eight distinct types, while the ROW contains nine.

Changes in Transect Mycorrhizae Summarized

Transect 1 in July 1991 is average in percent sheathed roots relative to the other transects and is characterized by high *Cenococcum* levels throughout the study (Table 5.4; Appendix V). In May 1992, total sheathed roots and infestation with *Cenococcum geophilum* and White Mycorrhiza increase well above mean levels within this transect (Fig. 5.7).

Transect 2 in July 1991 is low in mycorrhizae compared to the mean. In September 1991, this transect drops yet lower in total mycorrhizae while increasing in White Mycorrhiza

Table 5.3a: Mean percent sheathed roots of *Picea mariana* seedling at Waterhen within five ROW transects and in the adjacent undisturbed forest in July 1991, September 1991 and May 1992. Site means are also presented. (N = 6 for the July 1991 ROW transects; N = 4 for the September 1991 and May 1992 ROW transects. N = 3 for the forest transect collections. (Transect data for the Waterhen forest is not shown.)

Trans. No.	Total Sheathed Roots			*Cennococcum geophilum*			White Mycorrhiza			*Piloderma croceum*			Beige, Brown and other Mycorrhizas		
	JULY	SEPT	MAY	JULY	SEPT	MAY	JULY	SEPT	MAY	JULY	SEPT	MAY	JULY	SEPT	MAY
1	27.30	26.00	57.00	22.30	15.00	38.50	4.70	8.00	18.00	0.70	0.00	1.00	0.00	3.00	0.50
2	23.30	12.00	26.50	18.30	9.30	14.50	3.00	14.00	12.00	1.70	0.00	0.00	0.70	0.00	0.00
3	26.00	29.00	47.50	16.70	24.00	38.50	9.00	3.00	9.00	0.00	0.00	0.00	0.70	2.00	0.00
4	42.30	37.50	51.50	23.30	28.00	39.50	6.00	2.50	3.00	13.70	7.00	11.00	0.70	1.00	0.00
5	17.30	15.00	52.00	9.70	7.50	28.00	7.70	3.50	10.70	0.00	3.00	14.00	0.00	1.50	0.00
ROW	27.30	24.40	46.00	18.10	17.40	32.00	6.10	5.50	10.50	3.20	2.40	4.70	0.50	1.40	0.10
Forest	42.60	22.90	53.60	31.10	12.50	33.50	8.30	8.10	9.90	0.90	1.60	4.40	2.30	0.90	4.30

Table 5.3b: ANOVA results for the comparison of mycorrhizal infestations levels between the different transects within the ROW and forest at each collection time. ROW and forest transects (1 to 5) are compared at each collection time (ROW/forest comparisons are not made). (N = 6 for the July 1991 ROW transects; N = 4 for the September 1991 and May 1992 ROW transects. N = 3 for the forest transect collections).

Transects (1 - 5)	July 1991		September 1991		May 1992	
Compared	ROW	Forest	ROW	Forest	ROW	Forest
Sheathed Roots	0.05	NS	0.001	NS	NS	NS
Cenoccocum geophillum	NS	NS	0.01	NS	NS	NS
White Mycorrhiza	NS	NS	NS	NS	NS	NS
Piloderma croceum	0.05	0.001	NS	NS	0.01	NS
Beige Mycorrhiza	NS	NS	NS	NS	NS	NS
Brown Mycorrhiza	NS	NS	NS	NS	NS	NS

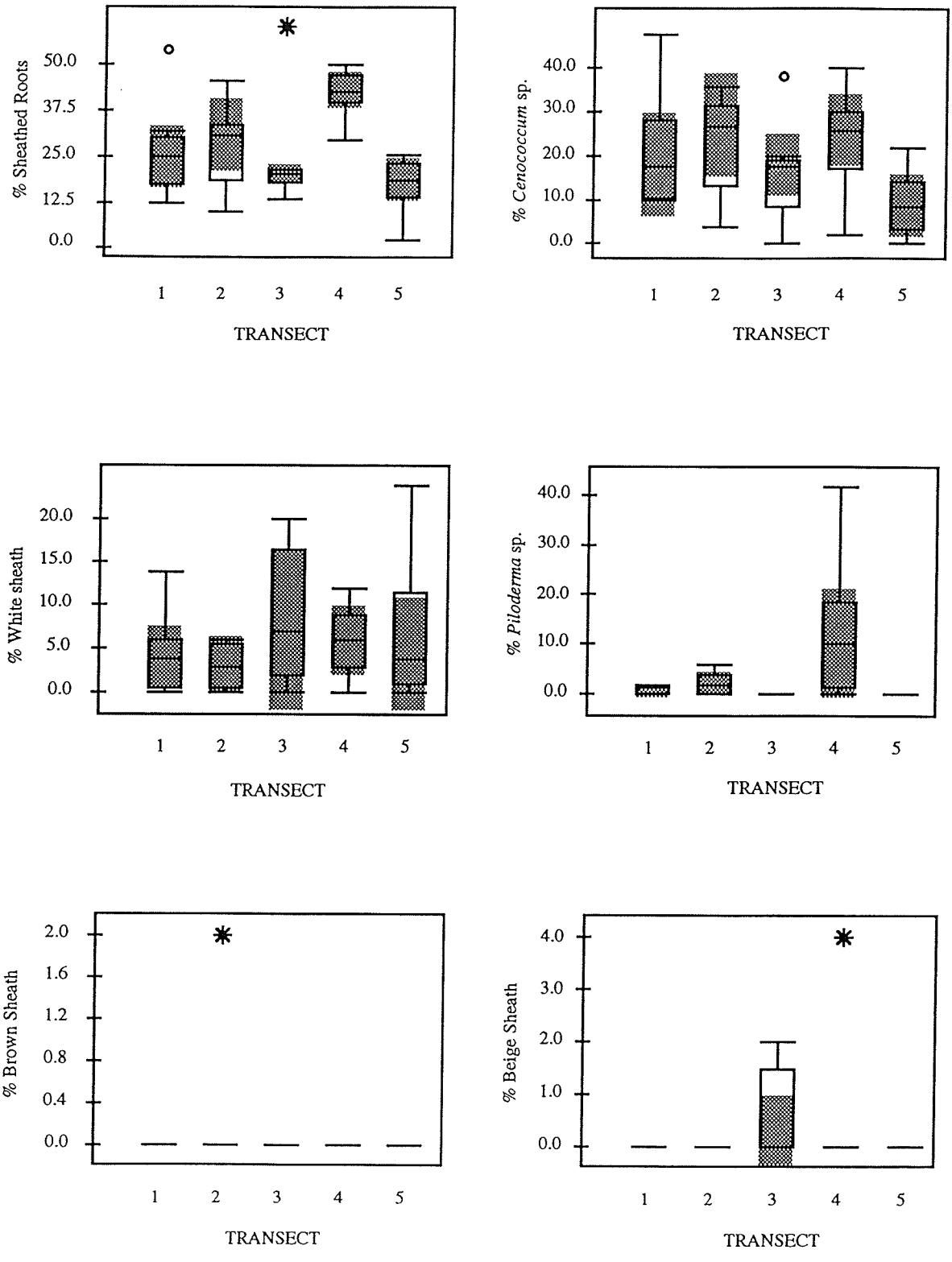


Figure 5.6. Transect differences in total sheathed roots and percent infestation of different symbionts at Waterhen in July 1991. Numbers are based on the mycorrhizal data from six root samples per transect.

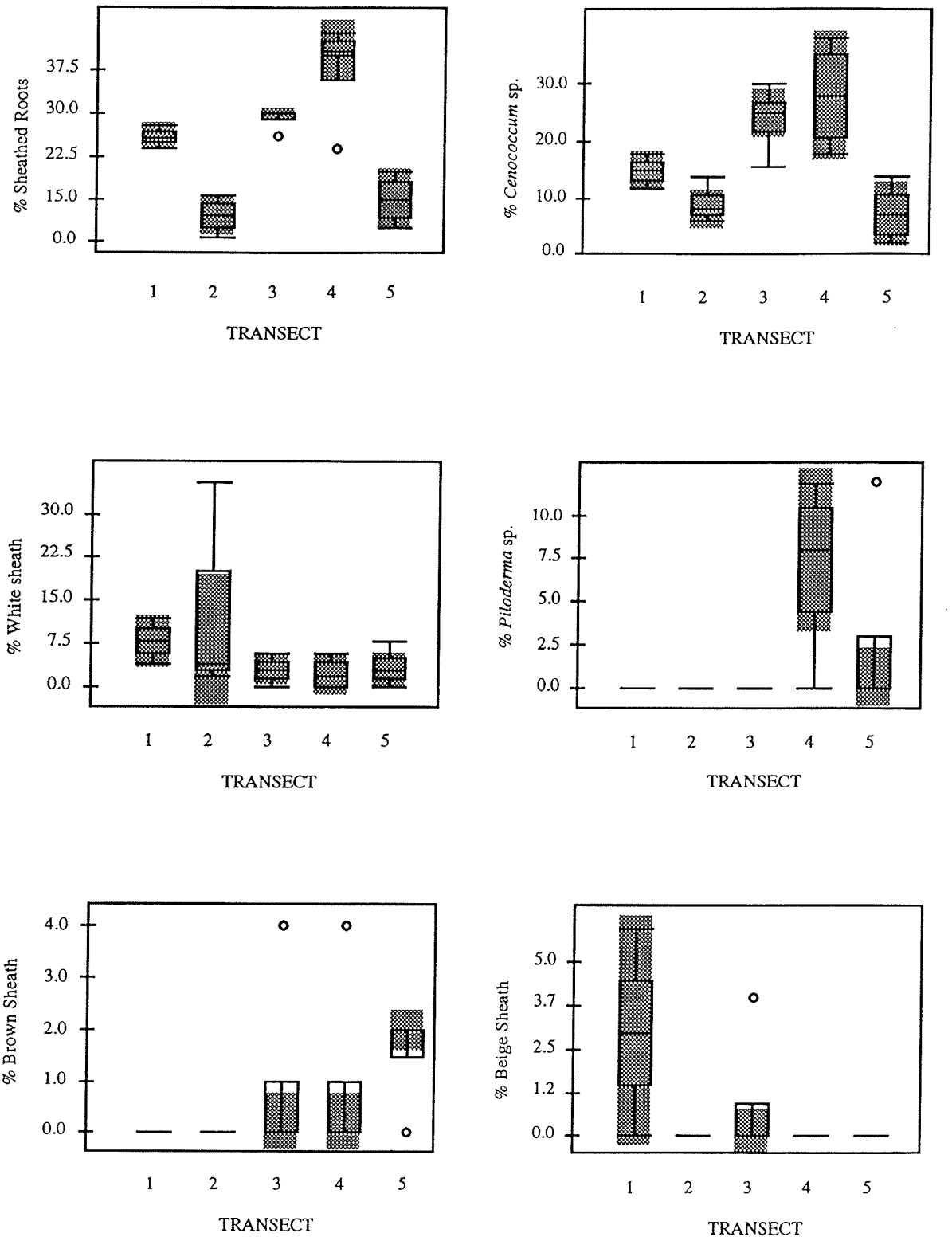


Figure 5.7. Transect differences in total sheathed roots and percent infestation of different symbionts at Waterhen in September 1991. Numbers are based on the mycorrhizal data from six root samples per transect.

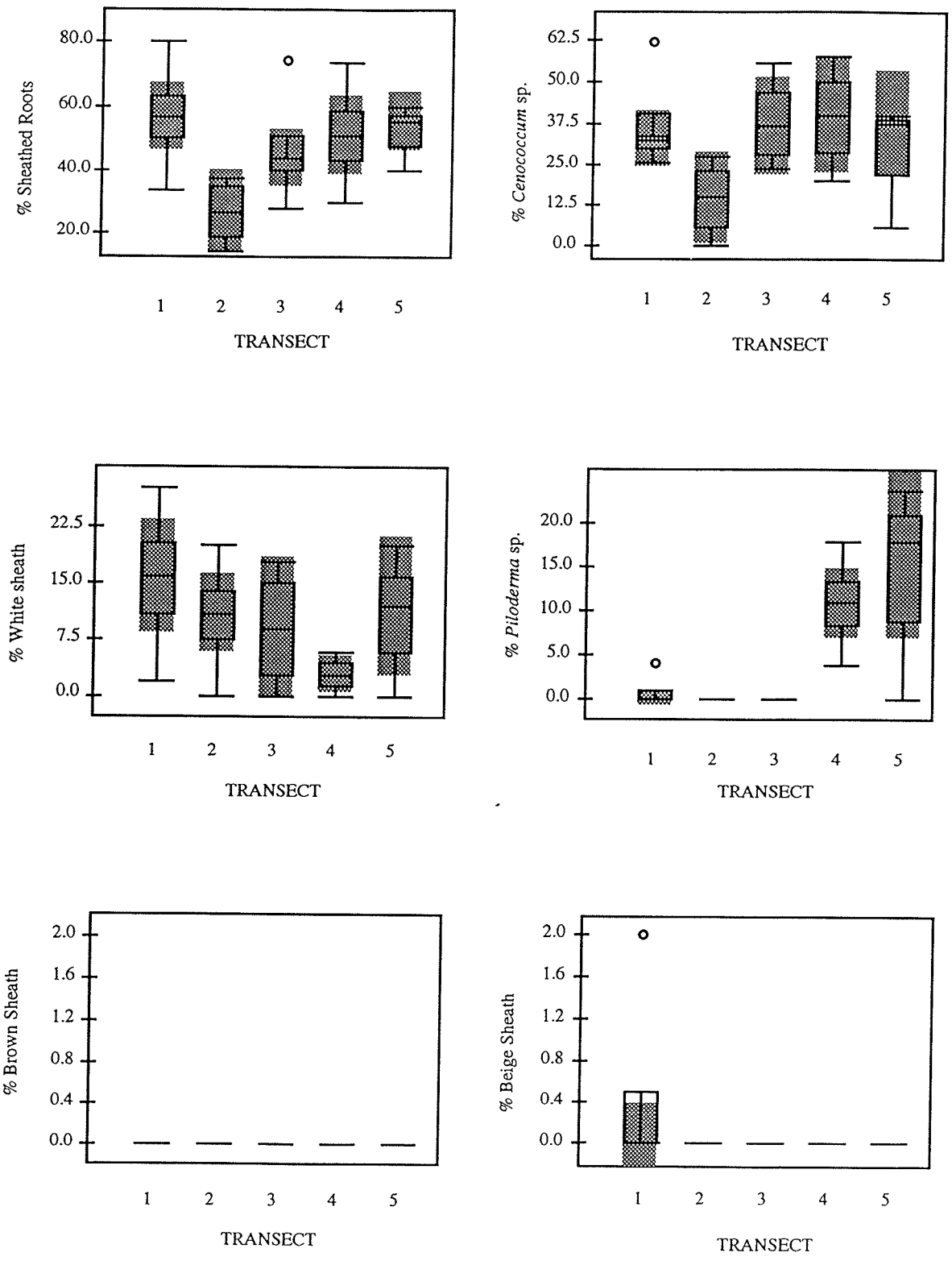


Figure 5.8. Transect differences in total sheathed roots and percent infestation of different symbionts at Waterhen in May 1992. Numbers are based on the mycorrhizal data from six root samples per transect.

by 11%. In May 1992, transect 2 is lower in infestation levels than other transects except in percent White Mycorrhizae, which is slightly above the mean.

Transect 3 in July 1991 is average in total sheathed roots and high in levels of *Cenococcum* and White Mycorrhiza. In September 1991, a slight increase in total mycorrhizae is a reflection of a moderate increase in *Cenococcum* countered by a decrease in White Mycorrhiza. In May 1992, *Cenococcum* and White Mycorrhiza increase by 14% and 6% respectively, resulting in high overall sheathed tip levels.

Transect 4 stands out above the other transects in July 1991 by 15% in mean percent sheathed roots ($p \leq .05$). This is primarily due to high levels of *Piloderma croceum* within this transect, being 11% greater here than in the other transects. *Cenococcum geophilum* is also above mean levels within this transect. *Cenococcum* levels are significantly higher within this transect compared to others ($p \leq .01$). In September 1991 this transect is above the mean in sheathed roots by 13%. In May 1992, increases in *Cenococcum* and *Piloderma* mycorrhizae result in above mean levels of total sheathed roots within this transect.

Transect 5 in July 1991 of all the transects is lowest in mycorrhizae. White Mycorrhiza is above mean levels, while *Cenococcum* and *Piloderma* are well below. This trend continues in September 1991, although *Piloderma* levels increase. In May 1992, a 37% increase in total percent sheathed roots brings this transect well above mean levels of total mycorrhizae. This is primarily due to increases in *Cenococcum*, *Piloderma* ($p \leq .01$) and White Mycorrhiza between September 1991 and May 1992.

Forest collections only show a significant difference ($p \leq .001$) between transect levels of *Piloderma croceum* in July 1991 (data not shown). Elevated levels of *Piloderma* were seen in the forest adjacent to ROW Transects 1 and 5. All other forest collections were uniform in levels of mycorrhizae overall. This shows a greater homogeneity for forest mycorrhizae as compared to the quite variable ROW habitat.

Woody Vegetation of ROW and Adjacent Forest

The Waterhen ROW site is a mature bog, extremely dense with seedlings of *Picea mariana* (Mill.) B.S.P. (85% of woody species), *Larix laricina* (Du Roi) Koch (4%), and *Populus tremuloides* Michx (1%). *Salix* spp. (9%), and *Betula glandulosa* Michx. (1%), make up the tall shrub component of the site (Table 5.6). A thick understory of *Ledum groenlandicum* Oeder, is present having a total 13% cover. *Vaccinium vitis-idaea* L., occupies over 38% of the low-ground cover with unidentified *Carex* spp. at 4%, and an unidentified grass species at 1%. *Sphagnum* moss covers 16.4% of the site and *Polytrichum* spp. another 8%. Lichens represent 8% of the total ground area. Litter, in the form of dead *Sphagnum* moss, covers 16% of the site.

Marked differences in density and diversity of woody species are seen among the ROW transects. Transect 1 is 97% spruce and 3% tamarack having a total tree density of 29,600trees/ha based on seedling numbers within the transect. Woody species diversity within this transect, as calculated using the Shannon-Weaver Index, is only 0.06. Transect 2 is 100% spruce at 30,800trees/ha. Transect 3 is 93% spruce, 3% tamarack, 1.5% poplar and 1.5% willow. This transect has 26,000trees/ha, and a woody diversity index of 0.14. Transect 4 is 80% *Picea mariana*, 8% *Larix laricina*, 2.5% *Populus tremuloides* and 9.5% *Salix* spp.. Target trees are at a density of 32,600trees/ha and the diversity index of the transect is 0.31. Transect 5 is 55% spruce, 8% tamarack, 1% poplar, 30.5% willow and 5.5% bog birch. This site reaches 47,000trees/ha and has a diversity index of 0.44. Overall tree density for the ROW is 33,200trees/ha.

Target tree density within the forest reaches 34,200 trees/ha and has much greater diversity than the ROW. *Picea mariana* dominantes the forest at 35% of the woody species composition, followed by 12% *Larix laricina*, 4.3% *Populus tremuloides*, 1.2% *Populus balsamifera*, 1.2% *Betula papyrifera*, 38.3% *Salix* spp., 3.7% *Lonicera dioca*, 0.6% *Cornus stolonifera* and 1.2% *Ribes* spp..

Table 5.6: Woody plant composition and density, expressed as relative density (%) and trees/ha, at Waterhen. Woody species diversity indices (SWI) are given for ROW transects. (ROW data results from sampling 23 meter square plots per transect.)

Plant Species	Transect No.				
	1	2	3	4	5
No. Trees Observed	68	71	60	75	108
Larix laricina (Du Roi) Koch	3%	-	3%	8%	8%
Picea mariana (Mill.) BSP.	97%	100%	93%	80%	55%
Populus tremuloides Michx.	-	-	1.5%	2.5%	1%
Populus balsamifera L.	-	-	-	-	-
Salix spp.	-	-	1.5%	9.5%	30.5%
Betula glandulosa Michx.	-	-	-	-	5.5%
Betula papyrifera Marsh.	-	-	-	-	-
Lonicera spp.	-	-	-	-	-
Cornus stolinefera Michx.	-	-	-	-	-
Ribes spp.	-	-	-	-	-
Trees/ha (x 10^4)	3.0	3.1	2.6	3.3	4.7
SWI	0.06	0	0.14	0.31	0.44

Mushrooms of the ROW and Adjacent Forest

A total of 56 mushrooms were collected within the ROW. Only two specimens each of *C. glaucopus* and *C. cinnamomeu* were found at this time in the adjacent forest. Mushroom fruiting body collections done within the ROW and adjacent forest in September 1991 reveal significant within-site differences in fungal diversity and species richness (Table 5.7). Transect 1 is the most diverse in fruiting bodies, having 23 fungi representing 6 species of the genus *Cortinarius*, including *C. glaucopus* Schaeff. ex Fr., *C. cinnamomeus* Fr., *C. varicolor* Fr., *C. cocoacolor* Fr., *C. anomalus* (Fr. ex Fr.), and *C. androasaceus* Fr.. Diversity is calculated as 0.64 using the Shannon-Weiner Index (SWI). Transect 2 is the next most diverse transect with a SWI of 0.30. A total of 20 fungi were collected: ten of the species, *C. cinnamomeus*, nine of *C. anomalous* and one of *C. semisanguine*. Transect 3 (SWI = 0.21) contained the same species as Transect 2 at lower numbers: four specimens of *C. cinnamomeus,* and one of *C. anomalous* and *C. semisanguine.* Transect 4 contained five specimens of *C. cinnamomeus* and one of *C. varicolor* and *C. semisanguine.* Diversity is rated at 0.20 for this transect. Transect 5 contained two specimens of *C. anomalus* and one of *Cantharellus cibarius* Fr. Diversity is rated at 0.28 for this transect. The site overall has a species richness of 7, and a SWI of 0.59.

Climatological Data

Monthly temperature maxima and minima for Waterhen are given in Figure 5.8a. Mean monthly precipitation is shown in Figure 5.8b. During the 1991 field season, mean maximum temperatures ranged from 25°C in July, to 28°C in August, to 17°C in September. Lows were at 10°C for July and August, and declined to 5°C in September. In May 1992, highes reached a mean of 17°C and lows reached 4°C. Absolute monthly precipitation (cm), shows the 1991 field season to be wet compared to 1990. Precipitation in July and September 1991 reached 11cm; August was relatively dry, reaching only 3cm.

Table 5.7: Numbers of fungal fruiting bodies collected at Waterhen in September 1991. Diversity (SWI) and species richness is given per transect.

Fungal Species	Transect number at Waterhen Research Site					
	1	2	3	4	5	Total
Cortinarius semisanguine Fr.		1	1	1		3
Cortinarius glaucopus Schaeff. ex Fr.	7					7
Cortinarius cinnamomeus Fr.	9	9	4	5		27
Cortinarius varicolor Fr.	1			1		2
Cortinarius cocaocolor Fr.	2					2
Cortinarius anomalus (Fr. ex Fr.)	3	10	1		2	16
Cortinarius androsaceus Fr.	1					1
Cantharellus cibarius Fr.					1	1
SWI	0.64	0.30	0.21	0.20	0.28	0.59
Species Richness	6	3	3	3	2	7

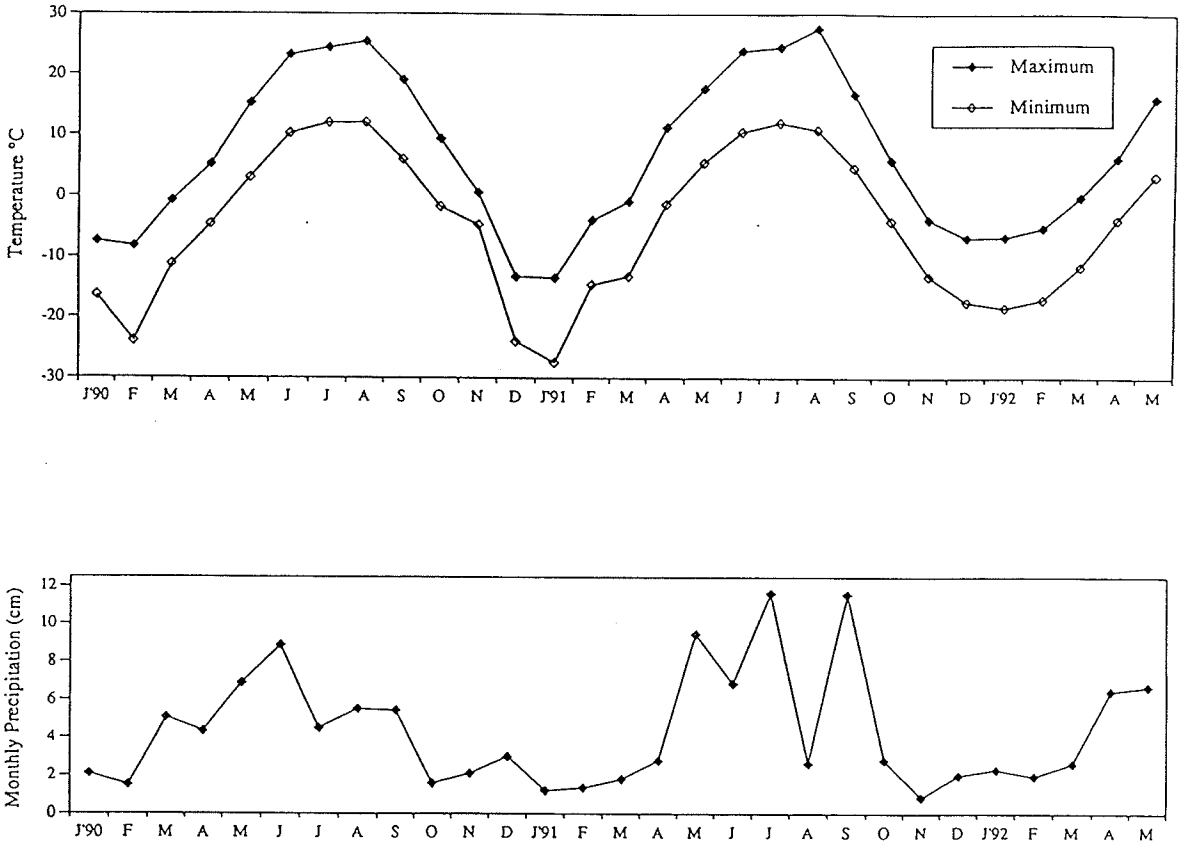


Figure 5.9. Monthly temperature maxima and minima and monthly precipitation (cm) from January 1990 to May 1992 are presented from Pine River, the nearest reporting station to Waterhen.

Soil Characteristics

Soil analysis of cores taken from each of the transects, reveal crude differences between the transects in percent moisture, pH, organic content, conductivity and bulk density (Table 5.8). The most outstanding difference is in the soil bulk density of Transects 4 and 5. Density reached .13 and .14 respectively, compared to .05 - .08 seen for transects 1 - 3. These levels more closely resemble forest levels. The pH of transect 5 is also similar to the more alkaline forest transects (mean 4.8), being 4.5 compared to 4.1 - 4.2 for the other transects. Conductivity measures within Transects 1 and 5 are similar, reaching 250μS, compared to 120 - 174μS for the other transects. These levels approximate forest levels which range from 175 - 580μS. Moisture content in Transects 4 and 5 soils, at 8.4 and 7.1%, respectively, are also similar to levels in forest soils which range from 5.7 to 9.7%. Other ROW transects range from 8.9 to 17.6%. Conductivity, pH and ml water/g soil of Transect 1 are similar to observed values in Transects 4 and 5.

DISCUSSION

Changes in Mycorrhizae After Herbicide Treatment

At dilute concentrations, several herbicides have been shown to act as stimulants to mycorrhizal activity (Sequeira et al. 1991; Dasilva et al. 1977; Smith and Ferry 1979). In this study, the increase in percent sheathed roots of ROW seedlings observed after herbicide application may reflect an effect of *Tordon* formulations on mycorrhizal fungi. The suppression of mycorrhizal infestations observed within the ROW in July 1991 (see Chapter IV of this thesis for comparison of other ROW sites) was followed by an increased level in the spring of 1992. The 20% increased levels in ROW mycorrhizae between July 1991 and May 1992 suggests that the *Tordon 101* treatment may not have suppressed mycorrhizal infestations. Prolific fruiting of ectotrophic fungi within the ROW after site treatment with *Tordon 101* also suggests that the herbicide may have acted as a stimulant to these fungi.

Table 5.8: Soil data from ROW and forest transects at Waterhen. Means (± S.D.) are calculated.

Soil Sample	ROW Transects					Forest Transects					Mean ± SD	
	1	2	3	4	5	1	2	3	4	5	ROW	Forest
% Soil moisture	83.8	87.3	84.4	79.8	80.5	82.8	75.7	73.4	79.7	83.3	83.2 ± 3.10	79.0 ± 4.30
Soil pH	4.2	4.2	4.1	4.1	4.5	4.4	4.3	5.0	5.0	5.3	4.2 ± 0.20	4.8 ± 0.40
Conduct. (μS)	246	120	168	174	263	175	256	580	503	336	194 ± 59	370 ± 169
% Organic	82.3	95.9	93.4	90.7	86.7	83.1	84.6	86.9	87.6	89.0	89.8 ± 5.40	86.2 ± 2.40
Density (g/ml)	0.08	0.05	0.08	0.13	0.14	0.10	0.13	0.16	0.20	0.20	0.1 ± 0.10	0.2 ± 0.20
ml water/g soil	8.92	17.6	13.2	8.36	7.1	9.65	7.13	5.73	6.2	6.91	11.0 ± 4.30	7.1 ± 1.50
ml water/ml soil	0.7	0.89	1.03	1.06	1.02	0.96	0.94	0.92	1.25	1.35	0.9 ± 0.10	1.1 ± 0.20

After herbicide treatment, between July 1991 and September 1991, physiological changes within the spruce seedlings can be expected to arrest plant functioning (Mullison 1985). Heightened stress of the target trees may create a greater demand for the symbionts, a phenomenon which is recognized by other studies of stress on the mycorrhizal symbiosis (Gehring and Whitham 1992). Root exudates, which increase after use of *Tordon 101* (Mullison 1985), can enhance mycorrhizal activity (Ratnayake et al. 1978). Thus, although an immediate augmentation of mycorrhizal infestations was not observed within the ROW, infestation levels in September 1991 may have dropped even lower than they did in the forest had not herbicides been applied. This observation is further supported in that the total percent sheathed roots and percent infestation with *Cenoccocum, Piloderma*, White, Brown and Beige mycorrhizae increased within certain transects between July 1991 and September 1991.

Judging by the high number of healthy green trees in May 1992, the effectiveness of the *Tordon 101* treatment was fairly low, suggesting that heavy rains after the time of application caused significant leaching of the active ingredients into the ground water. This in turn would have reduced the toxicity of the chemical, thus, favoring infestations by mycorrhizae. Tree and shrub death was, however, confirmed in the next growing season (May 1992), suggesting that herbicide residues might still have been present and active.

The ROW Habitat and Ectomycorrhizae

Lower levels of mycorrhizal infestation often occur in disturbed habitats compared to mature forest sites (Perry et al. 1989). In one study of Scots pine, *Pinus sylvestris* L., with results similar to my findings, the average percent mycorrhizae in managed sites was 20% compared to 60 - 85% in forest sites (Vare 1989). Ectomycorrhizal fungi, which are expected to predominate in the low nitrogen, acidic soils of Waterhen (Read 1991), are extremely dependant upon adequate moisture and aeration conditions for successful growth (Stenstrom 1991; Coutts and Nicoll 1990). In the Hydro ROW habitat, soils are more susceptible to desiccation from increased exposure to sun, high temperatures and wind and they may be

compacted by large all-terrain vehicles during and after corridor clearing (Magnusson and Stewart 1987). Thus, desiccation, elevated temperatures, wind exposure and soil compaction may be some of the reasons for the suppression of ROW mycorrhizal infestations.

At Waterhen, stand age of the adjacent forest was not greatly different from the ROW due to extensive forest fires which swept the area less than a decade prior to line construction. This helps to explain the similarity in frequency and diversity of mycorrhizae between the two sites. Other studies of ectomycorrhizae on tree roots reveal a similar composition of symbionts between disturbed and neighboring undisturbed sites (Danielson and Pruden 1989; Christy et al. 1982) as seen in the Waterhen transects.

Positive or negative feedback is known to occur with regard to levels of mycorrhizal infestation after site disturbance (Gehring and Whitham 1992; Vare 1989; Saif and Khan 1975). Hypothetically, if disturbance promotes an increase in the inoculum potential of mycorrhizae, this will in turn increase tree survival. Conversely, reduced inoculum potential will reduce tree survival as modelled (Figure 5.10). Studies of coniferous trees with and without mycorrhizae show that increased densities of symbionts leads to increased growth for all trees and improved site productivity (Perry et al. 1989). If, therefore, herbicide treatment of the ROW is stimulating mycorrhizal activity, this will enhance the survival of target trees and favor the establishment of seedlings, contrary to management objectives.

Succession and Mycorrhizae

Succession in mycorrhizal fungi occurs as a disturbed forest habitat recovers after herbicide application or clear-cutting treatment (Read 1992; Dighton 1991; Harvey et al. 1976). For example, the mycorrhizal fungus *Piloderma croceum* is associated with newer forest stands; *Cortinarius* spp. is common to mid-succession stands, and *Suillus*, *Boletes* and other larger mycorrhizal fungi are associated with mature stands (Dighton 1991). Such mycorrhizal succession may be important in explaining the different infestation levels and types of mycorrhizae observed between ROW and forest collections.

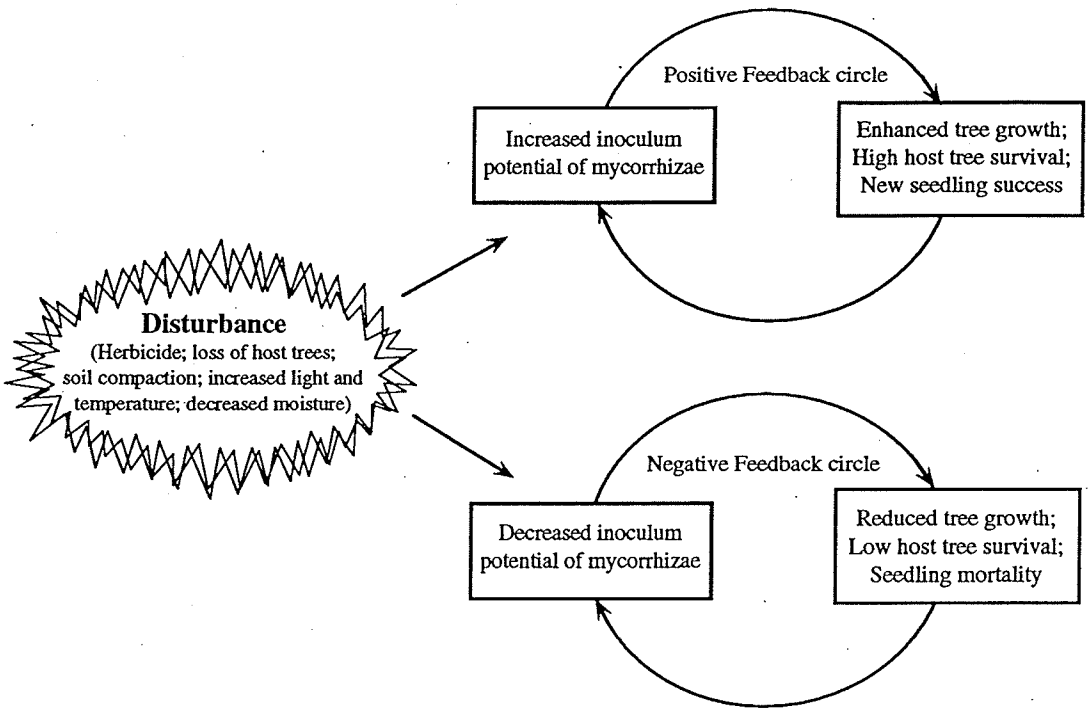


Figure 5.10: Relationship between mycorrhizal inoculum potential and tree seedling survival after disturbance (adapted from Perry et al. 1989).

In my study, the ROW site, having been cleared in 1974, is in mid-succession and contains numerous fruiting bodies of the genus *Cortinarius* and higher levels of *Piloderma* infestations within the ROW than the forest. No data is yet available on the nature of *Cenococcum geophilum* succession, but its ubiquitous distribution suggests an ability to readily colonize any area of adequate moisture and pH.

Distribution of Mycorrhizae

There are three recognized types of mycelial differentiation among ectomycorrhizae: 1) the fairy ring, 2) the irregular mat and 3) the dispersed colony (Ogawa 1985). These differentiated types are reflected in the distribution patterns observed for the fungi in the Waterhen transects.

However, *Cenococcum* in its distribution does not seem to fit into any of the above categories. Its ability to produce sclerotia insures its survival and promotes wide distribution (Shaw and Sidle 1983; Trappe 1969). Several studies have found *Cenococcum geophilum* levels to increase after burning (Pilz and Perry 1984; Dahlberg and Stenstrom 1991), thus the high levels of this symbiont observed in both the ROW and forest can be expected. Studies of mycorrhizal infestations on black spruce roots in Ontario also show that this symbiont predominates over other mycorrhizae (Brundrett et al. 1990). Also, *C. geophilum* shows marked host and habitat preferences (Malloch and Malloch 1981, 1982).

Piloderma, known for its patchiness (Dahlberg and Stenstrom 1991; Danielson and Visser 1989), is found at high densities in only two transects of the ROW and forest, following a dispersed distribution pattern. Its slow growth rate and narrow range of pH tolerance (Erland et al. 1990) contribute to its often poor competitive ability with other mycotrophs (Erland and Finlay 1992). The observed increase of *Piloderma croceum* frequency of infestation within the ROW from summer 1991 to spring 1992 may have been due to a multiplicity of factors including sampling disturbance acting as a major vector for mycorrhizal propagules (Dahlberg and Stenstrom 1991). Other studies in bog habitats, similar

to the Waterhen site, have shown *Cortinarius* to be the dominant genus of the forest (Dahlberg and Stenstrom 1991; Doudrick et al. 1990). *Cortinarius* is a fungus having the dispersed colony type of distribution. If the White Mycorrhiza of this site is formed by this fungus, it would explain its uniform distribution.

Transect Mycorrhizae Related to Vegetation, Mushrooms and Soil

Within-site variation in mycorrhizae may be related to the plant community (Jackson and Mason 1986; Schenk 1982; Dickenson and Lucas 1979). In our study, there is considerable variation in percent infestation of seedlings and colonization with individual symbionts within and between the different transects. The high below-ground biomass of target tree roots within transects high in spruce density are expected to provide increased surface area for mycorrhizal infestation as well as a sink for mycorrhizal inoculum. However, transects high in spruce density were not always highest in overall infestation.

Soil factors often correlate to specific mycorrhizal species (Erland and Soderstrom 1991; Erland et al. 1990). For example, transects 4 and 5, distinct in their high incidence of *Piloderma croceum*, are also more mineral in nature than other transects. These transects have a greater bulk density, lower soil moisture and, as in Transect 5, represent a more alkaline environment. *Cenococcum geophilum* infestations seem to be uniform thoughout all transects, regardless of soil characteristics.

One study examining the effect of fertilization on the production of epigeous basidiocarps by mycorrhizal fungi associated with loblolly pine, notes a failure to directly relate fruiting body density to increased levels of mycorrhizae (Menge and Grand 1978). At Waterhen it is interesting to note that in Transects 1 and 2 mushrooms of *Cortinarius* spp. were abundant and it was in these transects where the highest density of White Mycorrhiza was observed.

As only a fraction of the total seasonal production of mushrooms fruit in any one time period (Doudrick et al. 1990), other mycorrhizal forming mushrooms may have been present

at Waterhen which were not observed. It is estimated that mushrooms observed at a point in time only represent about five percent of the total number of fungal taxa forming mycorrhizae over the season (Taylor and Alexander 1990). At Waterhen, two of the most common mycorrhizae, *Cenococcum* and *Piloderma*, do not produce conspicuous fruiting structures and their living material represents the vast amount of unseen fungal material at the site.

Phenological Changes in Mycorrhizae

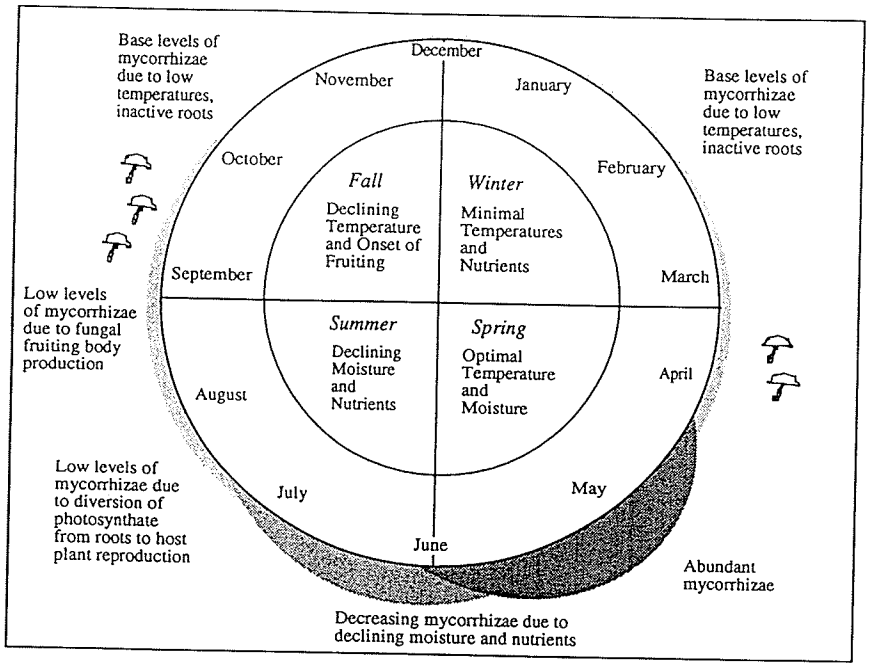
Several studies report seasonal fluctuations in mycorrhizal activity (Ietswaart et al. 1992; Coutts and Nicoll 1990; Brundrett and Kendrick 1988; Douds and Chaney 1986; Fogel 1980; Rabatin 1979). There is a narrow window of time over the year when temperature and moisture conditions in a temperate climate favor microbial activity. In the winter, tree dormancy and low soil temperatures limit mycorrhizal growth, and in the summer, hot and dry weather, such as occurs at Waterhen, diminishes fungal acitvity (Harvey et al. 1978). Wet soil habitats or wet seasons produce varying cycles of uniquely distinct mycorrhizal activity (Coutts and Nicoll 1990). Fungi may differ in their sensitivity to flooding, ranging from highly intolerant to resistant (Stenstrom 1991), but overall levels of infestation will be reduced in a waterlogged soil due to its low oxygen potential in contrast to a more mesic soil.

Herbicide treatment of a site will also interfere with normal phenological patterns and in many cases mycorrhizal infestation levels will drastically diminish (Trappe et al. 1984; Chakravarty and Chatarpaul 1990). Nutrient additions, including those from herbicide formulations which stimulate mycorrhizae, may augment mushroom fruiting body production and mycorrhizal levels during a given season (Menge and Grand 1978), although mycorrhizae are generally suppressed in highly fertilized soils (Douds and Chaney 1986; Read 1991).

Seasonal changes in mycorrhizal activity are clearly depicted in the forest data from Waterhen. The significant decrease of infestation levels follow predicted patterns of mycorrhizal activity for temperate regions. These patterns reflect the reduced temperatures of fall and concomitant reduced nutrient status of the plants. Harvey et al. (1978) confirm this

finding in an exhausitive study of ectomycorrhizae in a mature Douglas-fir/larch forest (*Psuedotsuga menziesii* (Mirb.) Franco and *Larix laricina* (Du Roi) Koch) in Western Montana.

A model (Figure 5.11a and b) summarizing mycorrhizal activity levels under different site and soil conditions is presented to represent the discussed seasonal patterns. Mycorrhizal activity is generally greatest in May when soil moisture is adequate and temperatures are favorable for growth. This is shown (Figure 11a) by an increase in the width of the shaded area associated with May. Diminished activity often occurs during the hotter summer months of July and August and increases again slightly in September. Fruiting body production at this time, shown by the mushrooms appearing adjacent to the fall months, and decreased metabolic activity of the host tree results in a natural reduction in mycorrhizal infestation rates. Depending upon the activity of the tree roots over the winter, mycorrhizal levels tend to stay at low or minimal levels. In the spring, increased temperatures and optimal moisture and nutrient conditions will again renew mycorrhizal activities. In wet conditions, mycorrhizal activity is much reduced during the spring and the peak of mycorrhizal activity is shifted to the hotter and drier summer and fall months (Figure 5.11b).



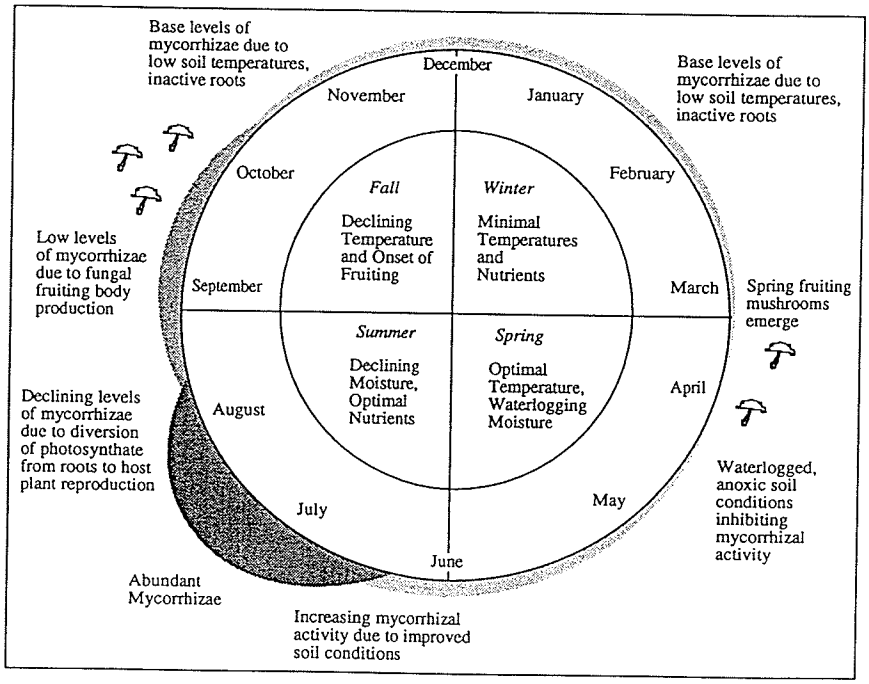


Figure 5.11: Model for summarizing mycorrhizal activity in temperate climate regions. The peak of mycorrhizal activity is in spring from April to May when soil moisture and temperature is optimal (a), or occurs in late July and August during wet sping seasons or in waterlogged soils after soil moisture has decreased (b).

CHAPTER CONCLUSION

In July 1991, there is a significant ROW/forest dichotomy in mycorrhizal levels of spruce seedlings. Percent mycorrhizal roots are a mean 15% lower ($p \leq .01$) within the ROW compared to the forest. September collections show a 20% decline in forest mycorrhizae ($p \leq .001$), while no decrease in colonization of ROW spruce saplings is observed. A 20% increase ($p \leq .001$) in mycorrhizae within the ROW in May 1992 (reaching up to forest levels of infestation) suggest that herbicides exert no overall negative effect on mycorrhizae, and in fact may stimulate mycorrhizal activity, possibly acting as a nutrient source. Both the ROW and forest sites exhibit expected phenological changes.

Eleven different mycorrhizal types are observed; three types are frequent and widely distributed, two have intermediate occurrence, while the others occur only intermittently. Colonization rates of *Cenococcum geophilum* are uniform throughout all ROW and forest transects. White Mycorrhiza, possibly of *Cortinarius* species origin, is more patchy in nature than *Cenococcum*, but is still at consistent levels over all the transects. The clumped nature of *Piloderma croceum*, reported by other authors, is observed in this study.

Differences in density and composition of vegetation between the transects generally correlate with observed mycological differences. Climatological data for the area supports the hypothesis that mycorrhizae infesting ROW and forest tree roots underwent phenological changes over the study period. Soil differences between the ROW and forest show a slightly more moist and acidic environment for fungi within the ROW. It is possible that some factor other than soil moisture is responsible for the dichotomy of ROW/forest mycorrhizal levels at Waterhen in July 1991. Dry conditions and high soil temperatures in the ROW environment may occur intermittantly and may be responsible for the suppressed infestation levels of mycorrhizae encountered in the corridor collections.

Stimulation of mycorrhizae by *Tordon 101*, if it is actually occuring, may increase the survival of coniferous trees within the ROW, thereby reducing management effeciency.

CHAPTER VI

RESEARCH CONCLUSIONS, OBSERVATIONS AND RECOMMENDATION TO HYDRO

RESEARCH CONCLUSIONS

1. There is a significant difference in mycorrhizal infestation of tree seedlings growing within the ROW compared to the adjacent forest (control) of most sites.
2. The similarity in mycorrhizal infestation levels between most sprayed and unsprayed ROW sites suggest that herbicide treatments with *Tordon 101* are not significantly reducing mycorrhizae within ROW sites. Differences between the ROW and forest in vegetation cover, soil moisture, light and aeration and not herbicides, are likely to be the major factors causing the dichotomy in mycorrhizal levels commonly observed between the ROW and forest.
3. ROW sites treated with *Tordon 10K* at Mafeking, Manitoba, manifest increased levels of mycorrhizal infestation.
4. Levels of mycorrhizal infestation of tree roots reflect expected phenological patterns as mediated by seasonal affects.
5. *Cenococcum geophilum* Fr. is the most abundant symbiont at all sites. *Piloderma croceum* Erikss. & Hjorts and eleven unidentified mycorrhizas, described as White, Soft-White, Brown, Beige, White-Yellow, Angel-White, Grey, Clear, Bright-White and Pink are also observed at lower frequencies and percent infestation of roots.
6. The most abundant mushrooms found fruiting at the research sites were of the genus *Cortinarius* (cf. *C. semisanguine* Fr., *C. glaucopus* Schaeff. ex Fr., *C. anomalus* (Fr. ex Fr.) Fr., *C. cinnamoneus* Fr., *C. cinnabariunus* Fr. and *C. androsaceus* Fr.). Other mycobionts are: *Hygrophorus borealis* Pk., *H. barkerensis* Smith& Hesler, *Hygrophorus* spp., *Russula delica* Fr., *R. emetica* (Fr.) Pers., *Entoloma salmoneum* (Pk.) Sacc., *Cystoderma amianthinum* (Scop. ex Fr.), *Clitocybe clavipes* (Fr.) Kummer, *Cantharellus cibarius* Fr., *C. umbonatus* Fr., *Riparitites tricholoma* (Fr.) Karsten, *Coltricia perennis* (Fr.) Murr. and *Hydnellum* cf. *diabolus* Banker.

7. Vegetation analysis of the different sites show spruce, *Picea mariana* (Mill.)B.S.P., jack pine, *Pinus banksiana* Lamb., poplar, *Populus tremuloides* Michx. and paper birch, *Betula papyrifera* Marsh., to be the most persistent problem trees in northern ROW corridors.

8. Non-target shrubs forming dense thickets include: speckled alder, *Alnus incana* (L.) Moench, willow, *Salix* spp., and bog birch, *Betula glandulosa* Michx.. Other tall shrubs found within the unsprayed ROW are: wild red raspberry, *Rubus idaeus* L., currants, *Ribes* spp., redosier dogwood, *Cornus stolonifera* Michx. and honeysuckle, *Lonicera caerulea* L.. Low shrubs occuring at high densities at later stages of ROW succession encompass: labrador tea, *Ledum groenlandicum* Oeder and leatherleaf, *Chamaedaphne calyculata* (L.) Moench. The remaining shrubs found in ROW sites are: juniper, *Juniperus horizontalis* Moench, sheep-laurel, *Kalmia polifolia* Wang., blueberry, *Vaccinium angustifolium* Ait., rose, *Rosa* spp., three-toothed saxifrage, *Saxifrage tricuspidata* Rottb. and Canada buffaloberry, *Shepherdia canadensis* (L.) Nutt.. Dry-ground cranberry, *Vaccinium vitis-idaea* L., swamp cranberry, *Oxycoccus microcarpus* Turcz., bearberry, *Arctostaphylos uva-ursi* (L.) Spreng and bunchberry, *Cornus canadensis* L. have a procumbent habit. Shrubby cinquefoil, *Potentilla fruiticosa* L. and Bicknell's geranium, *Geranium bicknellii* Britt. are shrub like perrenials in ROW sites. The most frequent herbaceous plants of the ROW are wild-lily-of-the-valley, *Maianthemum canadense* Desf., strawberry, *Fragaria virginiana* Dcne., northern bedstraw, *Galium boreale* L., fireweed, *Epilobium angustifolium* L., and dandelion, *Taraxacum officinale* Weber. These herbaceous species occur in several ROW research sites, and may be indicators of herbicide residues.

OBSERVATIONS AND RECOMMENDATION

Although the *Tordon* formulations being used for ROW management in Manitoba have not been shown to be toxic to mycorrhizal fungi, a temporary stimulation of mycorrhizal levels after their use may actually be serving to enhance tree survival and new seedling success within the ROW. This effect of phenoxy herbicides has been documented in laboratory studies with several mycorrhizal species. Ultimately, it appears that Picloram is controlling shrubs, and may have little suppressive effect on conifers in the long term. As shrubs are desirable for creation of stable communities in Hydro corridors, use of shrubs as an alternative management strategy might be employed.

When we learn how to love nature *deeply* enough

and truly commune with God

with a pure heart, like a child

we will simply ask trees not to grow

where they will come to harm

and out of reverence for life, they will not

When universities acknowledge this type of endeavor

we will not need man-made light

or Right-of-ways

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APPENDIX I

Herbicide Chemical Structures and Formulations

(after Worthing and Walker 1987)

PICLORAM FORMULATIONS

Tordon 101 (Solution)

INGREDIENTS: (%w/w, unless otherwise noted)

4-amino-3,5,6-trichloropicolinic acid (*Picloram*) triisopropanolamine	10.2%
2,4-dichloro-phenoxyacetic acid (*2,4-D*) triisopropanolamine salt	39.6%
Inert ingredients:	50.2%

Water; isopropanol; proprietary surfactant; triisopropanolamine

(240g a.e. picloram-potassium/l; 0.3-1.8 kg/ha on non-crop land)

Tordon 10K (Pellets)

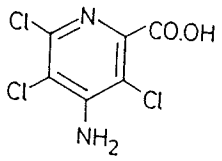
INGREDIENTS:

4-amino-3,5,6-trichloropicolinic acid (*Picloram*) triisopropanolamine

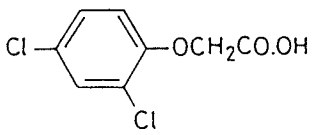
Inert ingredients: Clay

(20g or 100g a.i./kg; 2.2-9.5 kg picloram/ha)

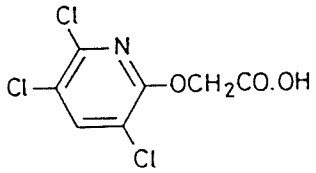
Picloram
4-amino-3,5,6-trichloropicolinic acid
$C_6H_2Cl_3N_2O_2$ (241.5)



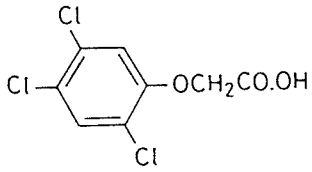
2,4-D
2,4-dichloro-phenoxyacetic acid
$C_8H_6Cl_2O_3$ (221.0)



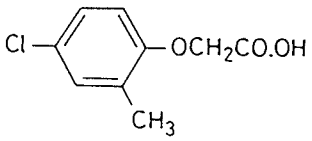
Triclopyr
3,5,6-trichloro-2-pyridyloxyacetic acid
$C_7H_4Cl_3NO_3$ (256.5)



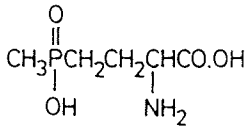
2,4,5-T
2,4,5-trichlorophenoxy acetic acid
$C_8H_5Cl_3O_3$ (255.5)



MCPA
4-chloro-2-methylphenoxyacetic acid
$C_9H_9ClO_3$ (200.6)



Glyphosate
N-(phosphonomethyl) glycine
$C_5H_{12}NO_4$ (181.1)



APPENDIX II

Site Designations and Number of Trees Sampled for Mycorrhizae Per Site

Site Designations

1976 SPRAY SITE	Trees Sampled
WSR and **WSF**: Transmission Line G31V, Tower 316.	115
Spruce 15 year old ROW and forest site, Waterhen, Manitoba	
Sapling root collections taken: July (45); Sept (35); May (35)	
1984 SPRAY SITES	
CSR and **CSF**: Transmission Line P58C, Tower 96-97.	20
Spruce 7 year old ROW and forest site, Cranberry Portage, Manitoba	
CTR and **CTF**: Transmission Line P58C, Tower 95-96.	20
Tamarack 7 year old ROW and forest site, Cranberry Portage, Manitoba	
SPR and **SPF**: Transmission Line P58C, Tower 74-75.	20
Jack pine 7 year old ROW and forest site, Sherridon Road, Manitoba	
CS[T]U: Transmission Line P58C, Tower 93-94.	20
Spruce and tamarack unsprayed site, Cranberry Portage, Manitoba	
SPU: Transmission Line P58C, Tower 74.	20
Jack pine unsprayed site, Sherridon Road, Manitoba	
1987 SPRAY SITES	
MS[T]R and **MS[T]F**: Transmission Line F10M, Tower 288-289.	40
Spruce and tamarack 4 year old ROW and forest site, Mafeking, Manitoba	
MPR and **MPF**: Transmission Line F10M, Tower 286-287.	20
Jack pine 4 year old ROW and forest site, Mafeking, Manitoba	
1990 SPRAY SITES	
ES[P]R and **ES[P]F**: Transmission Line P58C, Tower 221-222.	40
Spruce and jack pine 1 year old ROW and forest site, Egg Lake, Manitoba	
ESU: Transmission Line P58C, Tower 217-218.	10
Spruce unsprayed site, Egg Lake, Manitoba.	
Total:	325

APPENDIX III

Site Vegetation: Scientific and Common Names Used

(Nomenclature of vascular plants follows Scoggan (1978,1979),

Bryophytes follow Vitt, Marsh and Bovey (1988)

and Lichens follow Hale (1969)).

APPENDIX II

Species Name	Common Name
EQUISETACEAE	
Equisetum arvense L.	Common horsetail
Equisetum spp.	Horsetail family
PINACEAE	
Pinus banksiana Lamb.	Jack pine
Larix laricina (Du Roi) Koch	Tamarack
Picea glauca (Moench) Voss	White spruce
P. mariana (Mill.) BSP.	Black spruce
Juniperus horizontalis Moench	Creeping juniper
GRAMINEAE	
Poa spp.	Blue grass family
Poa pratensis L.	Kentuky blue grass
Elymus innovatus Beal	Hairy wild rye
Oryzopsis pungens (Torr.) Hitchc.	Northern rice grass
CYPERACEAE	
Carex sartwellii Dewey	Sartwell's sedge
Carex aenea Fern.	Silvery-flowered sedge
Carex spp.	Sedge species
JUNCACEAE	
Juncus spp.	Rush species
LILIACEAE	
Lilium spp.	Lily species
Maianthemum canadense Desf.	Wild lily-of-the-valley
ORCHIDACEAE	
Habenaria spp.	Bog orchid
Orchis rotundifolia Banks.	Round-leaved orchid
SALICACEAE	
Populus tremuloides Michx.	Trembling aspen
P. balsamifera L.	Balsam poplar
Salix spp.	Willow
BETULACEAE	
Alnus incana (L.) Moench	Speckled alder
Alnus crispa (Ait.) Pursh	Green alder
Betula glandulosa Michx.	Bog birch
Betula papyrifera Marsh.	Paper birch

Species Name	Common Name
SANTALACEAE	
Comandra umbellata (L.) Nutt.	Bastard toadflax
POLYGONACEAE	
Polygonum aviculare L.	Doorweed
CARYOPHYLLACEAE	
Cerastium arvense L.	Field chickweed
RANUNCULACEAE	
Anemone patens L.	Crocus anemone
Anemone multifida Poir.	Cut-leaved anemone
Caltha palustris L.	Marsh marigold
Ranunculus spp.	Buttercup family
FUMARIACEAE	
Corydalis aurea Willd.	Golden corydalis
SARRACENIACEAE	
Sarracenia purpurea L.	Pitcherplant
SAXIFRAGACEAE	
Saxifrage tricuspidata Rottb.	Three-toothed saxifrage
Ribes spp.	Currant family
ROSACEAE	
Rosa spp.	Rose family
Fragaria virginiana Dcne.	Smooth wild strawberry
Potentilla tridentata Ait.	Three-toothed cinquefoil
Potentilla fruiticosa L.	Shrubby Cinquefoil
Rubus chamaemorus L.	Cloudberry
Rubus idaeus L.	Wild red raspberry
LEGUMINOSEAE	
Vicia americana Muhl.	American vetch
Lathyrus ochroleucus Hook.	Cream-colored vetchling
GERANIACEAE	
Geranium bicknellii Britt.	Bicknell's geranium
BALSAMINACEAE	
Euphorbia esula L.	Leafy spurge
EMPETRACEAE	
Empetrum nigrum L.	Black crowberry

Species Name	Common Name
VIOLACEAE	
Viola cucullata Ait.	Northern bog violet
Viola spp.	Violet species
ELAEAGNACEAE	
Shepherdia canadensis (L.) Nutt.	Canada buffaloberry
ONAGRACEAE	
Epilobium angustifolium L.	Fireweed
UMBELLIFERAE	
Zizia aptera (Gray) Fern.	Heart-leaved alexander
CORNACEAE	
Cornus canadensis L.	Bunchberry
C. stolonifera Michx.	Red-osier dogwood
ERICACEAE	
Ledum groenlandicum Oeder	Labrador tea
Kalmia polifolia Wang.	Sheep-laurel
Chamaedaphne calyculata (L.) Moench	Leatherleaf
Andromeda polifolia L.	Bog-rosemary
Arctostaphylos uva-ursi (L.) Spreng.	Bearberry
Oxycoccus microcarpus Turcz.	Swamp cranberry
Vaccinium angustifolium Ait.	Blueberry
V. vitis-idaea L.	Dry-ground cranberry
PRIMULACEAE	
Steironema ciliatum (L.) Raf.	Fringed loosestrife
APOCYNACEAE	
Apocynum androsaemifolium L.	Spreading dogbane
LABIATAE	
Mentha arvensis L.	Field mint
SCROPHULARIACEAE	
Pedicularis lanceolata Michx.	Swamp loosewort
RUBIACEAE	
Galium boreale L.	Bedstraw
CAPRIFOLIACEAE	
Linnaea borealis L.	Twinflower
Lonicera caerulea L.	Blue Fly honeysuckle

Species Name	Common Name
COMPANULACEAE	
Campanula rotundifolia L.	Harebell

Species Name	Common Name
COMPOSITAE	
Solidago spp.	Goldenrod
Aster ciliolatus Lindl.	Lindley's aster
Aster spp.	Aster species
Petasites sagittatus (Banks) Gray	Arrow-leaved Colt's-foot
Petasites palmatus (Ait.) Gray	Palmate-leaved Colt's-foot
Taraxacum officinale Weber	Dandelion
Antennaria howellii Greene	Howell's Everlasting
Arctium minus (Hill) Bernh.	Lesser burdock

CRYPTOGAMS
ALGAE
Spirogyra spp.

MOSSES
Sphagnum spp.
Polytrichum spp.
Fissidens spp.
Bryum spp.
Mnium spp.

LICHENS
Cladonia rangiferina (L.) Wigg.
Cladonia pyxidata (L.) Hoffm.
Cladonia bellidiflora (Ach.) Schaer.
Cladonia gracilis (L.) Willd.
Cladonia chlorophaea (Flk.) Spreng.
Peltigera canina (L.) Willd.

APPENDIX IV

Site Mycorrhizal Data

for ROW, Unsprayed ROW and Forest Research Sites

(Seedling heights (cm), Percent Modified Roots, Non-mycorrhizal Roots, Superficially Infested Roots and Fully Sheathed Roots are given for each seedling and each mycorrhizal species. Overall site means, standard deviations and standard errors are shown.)

CRANBERRY PORTAGE '84 SPRUCE APPENDIX

Cranberry Portage '84 Spruce Mycorrhizae

Treatment	E/M	TH	NH	MR	SH	HN	SB	SW	SS	HNB	HNW	HNS
ROW	M	0.37	30	0	44	26	36	8	0	14	12	0
ROW	M	0.2	34	0	42	24	36	6	0	4	20	0
ROW	E	0.25	44	0	26	8	24	2	0	6	2	0
ROW	E	0.3	34	0	44	22	40	4	0	10	10	2
ROW	E	0.2	34	0	42	24	42	0	0	18	4	2
ROW	E	0.35	30	0	62	10	46	12	4	2	8	0
ROW	M	0.37	30	0	52	18	46	6	0	16	2	0
ROW	M	0.36	14	0	46	38	44	2	0	34	4	0
ROW	M	0.37	30	0	44	30	42	2	0	14	16	0
MEAN		0.31	31.11	0.00	44.67	22.22	39.56	4.67	0.44	13.11	8.67	0.44
SD		0.07	7.82	0.00	9.49	9.35	6.91	3.74	1.33	9.60	6.40	0.88
SE		0.02	2.61	0.00	3.16	3.12	2.30	1.25	0.44	3.20	2.13	0.29
Forest		0.3	6	4	44	50	40	30	0	28	4	26
Forest		0.25	0	10	26	74	32	28	0	34	24	32
Forest		0.37	4	0	46	50	8	46	0	14	48	0
Forest		0.38	0	4	30	70	30	4	0	46	34	0
Forest		0.5	0	0	34	66	42	2	0	54	2	0
Forest		0.65	0	2	34	66	36	0	0	60	6	0
Forest		0.35	0	2	38	62	38	0	0	62	0	0
Forest		0.38	12	16	28	60	28	6	6	54	2	6
Forest		0.3	14	0	50	36	36	38	0	34	4	2
Forest		0.4	18	4	56	34	56	0	0	32	2	0
MEAN		0.39	5.40	4.20	38.60	56.80	34.60	15.40	0.60	41.80	12.60	6.60
SD		0.11	6.87	5.12	10.02	13.83	12.19	18.04	1.90	15.76	16.76	12.04
SE		0.04	2.17	1.62	3.17	4.37	3.85	5.70	0.60	4.98	5.30	3.81
Unsprayed		0.24	28	4	34	46	28	6	0	32	12	2
Unsprayed		0.3	16	4	64	28	46	18	0	18	4	6
Unsprayed		0.37	18	2	46	38	28	22	0	16	22	2
Unsprayed		0.25	32	0	38	30	34	4	0	24	6	0
Unsprayed		0.2	10	34	68	22	62	6	0	8	14	0
Unsprayed		0.26	20	8	68	10	64	4	0	6	4	0
Unsprayed		0.25	22	0	56	22	44	12	0	12	10	0
Unsprayed		0.25	18	0	56	26	52	4	0	18	8	0
Unsprayed		0.23	14	0	52	34	50	2	0	22	14	2
Unsprayed		0.27	26	0	52	22	50	2	0	4	16	2
MEAN		0.26	20.40	5.20	53.40	27.80	45.80	8.00	0.00	16.00	11.00	1.40
SD		0.05	6.72	10.46	11.66	10.00	12.66	6.99	0.00	8.74	5.75	1.90
SE		0.01	2.12	3.31	3.69	3.16	4.00	2.21	0.00	2.76	1.82	0.60

*Note: SD (Standard Deviation); SE (Standard Error); E/M (Edge/middle of ROW); TH (Tree Height (m)); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net); SW (Superficial White); SB (Superficial Black); SS (Superficial Soft white); HNB (Hartig Net Black); HNW (Hartig Net White); HNS (Hartig Net Soft white);

MAFEKING '87 SPRUCE APPENDIX

Mafeking '87 Spruce Mycorrhizae

Treatment	TH	MR	NH	SH	HN	SW	SB	SBr	SS	SY	HNB	HNW	HNBr	HNS	HNBe	HNCl	HNWa
ROW	55	30	16	24	60	10	18	0	0	0	20	40	0	0	0	0	0
ROW	15	6	38	18	44	4	16	0	0	0	14	34	0	0	0	0	0
ROW	20	36	38	18	44	12	6	0	0	0	12	30	0	2	0	0	0
ROW	26	12	20	12	76	14	8	0	0	0	40	38	0	0	0	0	0
ROW	33	24	44	34	22	30	8	0	2	0	2	20	0	0	0	0	0
ROW	50	42	26	48	26	42	2	6	0	0	8	12	4	0	0	0	0
ROW	30	38	18	20	62	16	4	6	0	0	56	0	4	0	2	0	0
ROW	80	58	10	14	80	6	8	0	0	0	78	0	2	0	0	0	0
ROW	25	56	14	44	42	24	6	14	0	0	22	14	4	0	2	0	0
MEAN	37.11	33.56	24.89	25.78	50.67	17.56	8.44	2.89	0.22	0.00	28.00	20.89	1.56	0.22	0.44	0.00	0.00
SD	20.75	17.77	12.25	13.13	20.35	12.32	5.27	4.91	0.67	0.00	25.14	15.46	1.94	0.67	0.88	0.00	0.00
SE	6.92	5.92	4.08	4.38	6.78	4.11	1.76	1.64	0.22	0.00	8.38	5.15	0.65	0.22	0.29	0.00	0.00

	TH	MR	NH	SH	HN	SW	SB	SBr	SWa	SY	HNB	HNW	HNBr	HNS	HNBe	HNCl	HNWa
Forest	50	76	22	12	66	36	30	0	0	16	30	42	0	0	0	0	0
Forest	20	8	16	12	72	14	2	0	0	0	40	26	0	10	0	0	0
Forest	50	10	28	28	44	26	2	0	0	0	6	26	6	2	4	0	0
Forest	37	12	12	16	72	8	2	0	16	0	26	2	0	0	0	4	42
Forest	20	20	18	22	60	4	2	4	20	0	32	2	0	0	14	0	12
Forest	20	0	16	24	60	0	6	0	28	0	12	0	0	0	0	0	48
Forest	45	28	4	40	56	40	4	0	0	0	46	8	2	0	0	0	0
Forest	50	58	16	22	62	12	4	6	0	0	52	4	6	0	0	0	0
Forest	40	24	16	28	56	8	24	0	0	0	54	2	0	0	0	0	0
Forest	40	16	8	32	60	48	2	0	0	0	32	20	4	0	4	0	0
MEAN	36.89	26.22	16.44	22.67	60.89	16.44	8.44	1.11	7.11	1.78	33.11	12.44	1.56	1.33	2.00	0.44	11.33
SD	13.45	25.05	6.54	8.89	8.72	14.24	10.71	2.26	11.10	5.33	16.77	15.06	2.60	3.32	4.69	1.33	19.54
SE	4.02	7.54	2.12	2.81	2.60	5.29	3.26	0.68	3.38	1.60	5.00	4.55	0.81	1.00	1.41	0.40	5.94

*Note: TH (Tree Height (cm)); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net) SW (Superficial White); SB (Superficial Black); SBr (Superficial Brown); SS (Superficial Soft white); SY (Superficial Yellow); SWa (Superficial White angel); HNB (Hartig Net Black); HNW (Hartig Net White); HNBr (Hartig Net Brown); HNS (Hartig Net Soft white); HNBe (Hartig Net Beige); HNCl (Hartig Net Clear); HNWa (Hartig Net White angel); SD (Standard Deviation); SE (Standard Error)

EGGLAKE '90 SPRUCE APPENDIX

Egglake '90 Spruce Mycorrhizae

Treatment	TH	MR	NH	SH	HN	SW	SB	SBr	SY	HNB	HNW	HNBr	HNY	HNS	HNBe
ROW	25	42	26	52	26	42	6	6	0	10	8	8	0	0	0
ROW	40	50	16	52	32	40	12	10	0	12	18	2	0	0	0
ROW	14	4	30	42	16	36	8	0	2	16	0	0	0	0	0
ROW	23	24	36	52	18	34	24	0	0	8	10	0	0	0	0
ROW	23	14	44	24	32	24	0	0	0	8	24	2	0	2	0
ROW	12	54	48	16	36	16	0	0	0	8	22	6	0	0	0
ROW	24	92	74	14	12	14	0	0	0	8	0	4	0	0	0
ROW	31	54	62	22	16	8	8	8	0	6	0	6	0	0	4
ROW	39	24	34	26	40	24	6	0	0	4	36	0	0	0	0
ROW	27	64	36	30	34	28	2	0	0	6	28	0	0	0	0
MEAN	25.80	42.20	40.60	33.00	26.20	26.60	6.60	2.40	0.20	8.60	14.60	2.80	0.00	0.20	0.40
SD	9.15	26.27	17.18	15.18	9.95	11.51	7.37	3.98	0.63	3.41	12.89	3.01	0.00	0.63	1.26
SE	2.89	8.31	5.43	4.80	3.15	3.64	2.33	1.26	0.20	1.08	4.08	0.95	0.00	0.20	0.40

	TH	MR	NH	SH	HN	SW	SB	SBe	SY	HNB	HNW	HNWa	HNY	HNS	HNBe
Forest	40	0	2	22	76	36	30	0	16	30	42	0	10	0	0
Forest	23	12	8	18	74	0	6	8	18	24	2	0	38	0	10
Forest	11	0	0	14	86	20	10	0	0	16	0	72	0	0	4
Forest	26	2	6	18	76	6	20	0	6	42	26	0	10	0	0
Forest	32	24	8	12	80	14	10	0	0	32	20	40	0	0	4
Forest	31	4	4	12	84	8	10	0	0	40	4	48	0	0	2
Forest	23	2	6	16	78	16	12	0	0	34	2	46	0	0	0
Forest	25	8	6	6	88	6	10	0	8	52	18	0	14	8	0
Forest	15	4	8	36	56	38	22	0	0	40	28	0	0	0	8
Forest	20	0	10	34	56	2	20	0	24	28	2	0	34	0	0
MEAN	24.60	5.60	5.80	18.80	75.40	14.60	15.00	0.80	7.20	33.80	14.40	20.60	10.60	0.80	2.80
SD	8.42	7.53	3.05	9.58	11.20	13.33	7.56	2.53	9.05	10.22	14.54	27.81	14.42	2.53	3.68
SE	2.66	2.38	0.96	3.03	3.54	4.22	2.39	0.80	2.86	3.23	4.60	8.79	4.56	0.80	1.16

Treatment	TH	MR	NH	SH	HN	SW	SB	SBr	SWy	SGr	HNW	HNB	HNBr	HNWy	HNGr
Unsprayed	16	34	34	48	18	38	8	2	0	0	2	12	4	0	0
Unsprayed	20	44	36	22	42	24	0	0	2	0	4	18	4	10	6
Unsprayed	28	26	30	20	50	12	6	2	0	0	2	48	0	0	0
Unsprayed	26	20	48	28	24	10	8	12	0	0	0	20	4	0	0
Unsprayed	27	26	32	46	22	38	6	0	0	4	2	20	0	0	0
Unsprayed	30	44	10	42	48	32	10	0	4	4	10	32	0	6	0
Unsprayed	23	58	14	28	58	10	16	2	0	0	0	58	0	0	0
Unsprayed	20	28	14	58	28	24	22	0	6	10	6	2	0	14	6
Unsprayed	25	16	22	40	38	18	22	0	0	2	0	38	0	0	0
Unsprayed	24	10	48	42	10	18	8	0	0	16	2	0	2		6
MEAN	23.90	30.60	28.80	37.40	33.80	22.40	10.60	1.80	1.20	3.60	2.80	24.80	1.40	3.33	1.80
SD	4.25	14.61	13.60	12.37	15.70	10.74	7.18	3.71	2.15	5.40	3.16	19.03	1.90	5.39	2.90
SE	1.35	4.62	4.30	3.91	4.97	3.40	2.27	1.17	0.68	1.71	1.00	6.02	0.60	1.80	0.92

*Note: TH (Tree Height (cm)); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net) SW (Superficial White); SB (Superficial Black); SBr (Superficial Brown); SWy (Superficial White yellow); SY (Superficial Yellow); SGr (Superficial Grey); HNB (Hartig Net Black); HNW (Hartig Net White); HNBr (Hartig Net Brown); HNWy (Hartig Net White yellow); HNBe (Hartig Net Beige); HNG (Hartig Net Grey); HNWa (Hartig Net White angel);

Sherridon Road '84 Jack Pine Mycorrhizae

Treatment	E/M	TH	MR	NH	SH	HN	SW	SB	SS	SBr	SCl	HNB	HNW	HNS	HNBr	HNCl
ROW	E	25	60	32	6	62	4	4	0	0	0	6	10	0	48	0
ROW	M	16	34	46	16	36	12	4	2	0	0	6	12	18	6	0
ROW	E	20	20	66	20	14	22	4	0	0	0	4	8	0	2	0
ROW	M	46	14	32	8	60	6	2	0	0	0	44	10	0	6	0
ROW	M	25	52	32	16	52	12	6	0	6	0	28	16	0	14	0
ROW	M	10	24	24	32	44	26	12	0	0	0	28	10	2	6	0
ROW	M	30	16	26	60	14	64	10	0	12	0	12	2	0	0	0
ROW	E	20	18	32	24	44	24	0	0	2	0	0	42	2	0	0
ROW	E	43	40	8	18	64	14	12	0	0	2	24	10	2	12	16
ROW	M	35	12	50	32	18	34	2	0	0	0	6	4	6	2	0
MEAN		27.00	29.00	34.80	23.20	40.80	21.80	5.60	0.20	2.00	0.20	15.80	12.40	3.00	9.60	1.60
SD		11.58	16.82	15.89	15.55	19.67	17.55	4.30	0.63	4.00	0.63	14.34	11.11	5.60	14.29	5.06
SE		3.66	5.32	5.03	4.92	6.22	5.55	1.36	0.20	1.26	0.20	4.54	3.51	1.77	4.52	1.60

Treatment	TH	MR	NH	SH	HN	SB	SW	SS	HNB	HNW	HNS	HNBr	HNWa	HNG
Forest	18	0	28	32	40	4	28	0	14	26	0	0	0	0
Forest	39	4	24	20	56	0	20	0	12	42	2	2	0	0
Forest	53	44	12	12	76	2	10	0	12	18	0	36	0	0
Forest	12	4	26	14	60	2	12	0	18	40	2	0	0	0
Forest	35	2	38	14	48	12	0	4	40	0	6	0	2	0
Forest	42	8	20	14	66	0	0	14	14	0	52	0	0	0
Forest	31	2	40	6	54	0	0	6	8	0	46	0	0	0
Forest	28	0	32	22	46	4	0	18	18	0	28	0	0	0
Forest	27	8	10	14	76	0	0	14	2	0	72	0	0	4
Forest	21	0	20	6	74	2	0	6	60	0	16	0	0	0
MEAN	30.60	7.20	25.00	15.40	59.60	2.60	7.00	6.20	19.80	12.60	22.40	3.80	0.20	0.40
SD	12.19	13.27	9.99	7.72	13.06	3.66	10.21	6.83	17.24	17.56	25.97	11.33	0.63	1.26
SE	3.86	4.20	3.16	2.44	4.13	1.16	3.23	2.16	5.45	5.55	8.21	3.58	0.20	0.40

Treatment	TH	MR	NH	SH	HN	SW	SB	SBr	SY	SBe	HNB	HNW	HNG	HNY	HNBr	HNBe
UNSPR	28	14	46	16	38	0	16	0	0	0	20	0	0	0	18	0
UNSPR	13	14	64	22	14	16	6	0	0	0	8	0	0	0	6	0
UNSPR	26	6	24	24	52	0	2	0	32	0	24	2	4	24	0	0
UNSPR	17	48	36	32	32	24	10	0	0	0	8	6	0	0	16	2
UNSPR	38	22	46	6	48	0	6	0	0	0	40	0	0	0	6	2
UNSPR	60	2	62	18	20	0	18	0	0	0	20	0	0	0	0	0
UNSPR	62	8	44	6	50	2	2	2	0	0	42	8	0	0	2	0
UNSPR	21	32	66	14	20	0	8	6	0	0	10	6	0	0	4	0
UNSPR	45	20	20	2	78	0	0	0	6	0	68	0	0	14	4	0
UNSPR	28	18	50	4	46	0	4	0	0	0	46	0	0	0	0	0
MEAN	33.80	18.40	45.80	14.40	39.80	4.20	7.20	0.80	3.80	0.00	28.60	2.20	0.40	3.80	5.60	0.40
SD	17.10	13.53	15.85	9.88	19.24	8.56	5.98	1.93	10.09	0.00	19.80	3.19	1.26	8.35	6.45	0.84
SE	5.41	4.28	5.01	3.12	6.08	2.71	1.89	0.61	3.19	0.00	6.26	1.01	0.40	2.64	2.04	0.27

*Note: TH (Tree Height (cm)); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net); SW (Superficial White); SB (Superficial Black); SBr (Superficial Brown); SS (Superficial Soft white); SY (Superficial Yellow); SWa (Superficial White angel); HNB (Hartig Net Black); HNW (Hartig Net White); HNBr (Hartig Net Brown); HNS (Hartig Net Soft white); HNBe (Hartig Net Beige); HNCl (Hartig Net Clear); HNWa (Hartig Net White angel); HNG (Hartig Net Grey); SD (Standard Deviation); SE (Standard Error)

MAFEKING '87 JACK PINE APPENDIX

Mafeking '87 Jack Pine Mycorrhizae

Treatment	TH	MR	NH	SH	HN	SW	SB	SWy	SBe	HNW	HNB	HNWy	HNBe	HNG
ROW	60	56	10	8	82	0	8	0	0	0	82	0	0	0
ROW	78	82	6	2	92	34	0	0	0	0	92	0	0	0
ROW	32	38	12	14	74	20	8	0	0	0	74	0	0	0
ROW	43	34	6	16	78	22	10	4	0	4	64	10	0	2
ROW	46	52	4	10	86	16	10	0	0	0	86	0	0	0
ROW	70	60	8	16	76	26	6	0	0	2	76	0	0	0
ROW	28	42	20	20	60	8	14	0	0	0	60	0	0	0
ROW	57	30	8	16	76	30	8	0	0	0	76	0	0	0
ROW	62	38	10	30	60	18	16	0	0	6	54	0	0	0
ROW	64	36	28	30	42	20	8	0	0	2	40	0	0	0
MEAN	54.00	46.80	11.20	16.20	72.60	19.40	8.80	0.40	0.00	1.40	70.40	1.00	0.00	0.20
SD	16.28	15.87	7.38	8.87	14.73	9.98	4.34	1.26	0.00	2.12	15.85	3.16	0.00	0.63
SE	5.15	5.02	2.33	2.80	4.66	3.16	1.37	0.40	0.00	0.67	5.01	1.00	0.00	0.20

Treatment	TH	MR	NH	SH	HN	SW	SB	SWy	SBe	HNW	HNB	HNWy	HNBe	HNG
FOREST	Adult	50	8	10	82	8	10	0	0	0	80	2	0	0
FOREST	Adult	60	20	18	62	4	14	0	0	0	62	0	0	0
FOREST	Adult	44	0	12	88	14	4	0	0	2	86	0	0	0
FOREST	Adult	48	4	8	88	8	4	0	0	0	88	0	0	0
FOREST	Adult	22	14	26	60	12	16	0	0	4	56	0	0	0
FOREST	Adult	32	8	14	78	6	10	0	0	0	78	0	0	0
FOREST	Adult	26	4	32	64	14	24	0	0	2	62	0	0	0
FOREST	Adult	34	18	28	54	26	12	0	0	2	52	2	0	0
FOREST	Adult	40	8	8	84	8	4	0	0	0	80	2	2	0
FOREST	Adult	44	6	8	86	4	8	0	4	0	84	0	2	0
MEAN		40.00	9.00	16.40	74.60	10.40	10.60	0.00	0.40	1.00	72.80	0.60	0.40	0.00
SD		11.62	6.41	9.13	13.13	6.59	6.33	0.00	1.26	1.41	13.37	0.97	0.84	0.00
SE		3.68	2.03	2.89	4.15	2.08	2.00	0.00	0.40	0.45	4.23	0.31	0.27	0.00

*Note: TH (Tree Height (cm)); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net); SW (Superficial White); SB (Superficial Black); SY (Superficial Yellow); SWy (Superficial White yellow) HNB (Hartig Net Black); HNW (Hartig Net White); HNWy (Hartig Net White yellow); HNG (Hartig Net Grey); HNBe (Hartig Net Beige); SD (Standard Deviation); SE (Standard Error)

EGG LAKE '90 JACK PINE APPENDIX

Egg Lake '90 Jack Pine Mycorrhizae

Treatment	TH	MR	NH	SH	HN	SW	SB	SY	SWy	SBe	HNW	HNB	HNY	HNBe	HNS
ROW	48	36	56	34	10	32	4	0	0	0	6	4	0	0	0
ROW	90	48	14	28	58	26	4	0	0	0	8	44	0	0	8
ROW	45	68	22	36	42	30	14	0	0	0	14	24	0	4	0
ROW	15	26	44	58	18	54	4	0	0	0	2	16	0	0	0
ROW	45	36	30	56	14	44	20	0	0	0	2	12	0	0	0
ROW	10	20	12	62	26	48	18	0	0	0	0	26	0	0	0
ROW	32	32	18	38	44	8	32	0	0	0	2	42	0	0	0
ROW	24	4	16	58	26	42	12	0	8	0	8	18	0	0	0
ROW	57	42	40	34	26	20	14	0	0	0	12	6	0	0	8
ROW	60	18	22	58	20	52	0	8	0	0	8	10	2	0	0
MEAN	42.60	33.00	27.40	46.20	28.40	35.60	12.20	0.80	0.80	0.00	6.20	20.20	0.20	0.40	1.60
SD	23.76	17.75	14.73	13.18	15.08	14.96	9.68	2.53	2.53	0.00	4.66	13.93	0.63	1.26	3.37
SE	7.51	5.61	4.66	4.17	4.77	4.73	3.06	0.80	0.80	0.00	1.47	4.41	0.20	0.40	1.07

Treatment	TH	MR	NH	SH	HN	SW	SB	SY	SWy	SBe	HNW	HNB	HNY	HNWy	HNBe
FOREST	Adult	14	14	40	46	12	28	0	0	0	2	42	0	0	2
FOREST	Adult	24	22	20	58	10	14	0	0	0	6	52	0	0	0
FOREST	Adult	24	12	26	62	24	0	0	6	0	6	36	0	22	0
FOREST	Adult	12	8	44	48	12	10	54	0	0	0	20	28	0	0
FOREST	Adult	18	20	34	46	12	14	18	0	0	0	44	2	0	2
FOREST	15	44	10	38	52	30	20	0	0	0	12	42	0	0	0
FOREST	Adult	12	4	26	70	0	4	64	0	0	0	58	14	0	0
FOREST	Adult	40	22	32	46	2	6	34	0	4	0	30	12	0	4
FOREST	Adult	44	12	38	50	38	8	0	0	0	4	46	0	0	0
FOREST	Adult	32	32	28	40	20	8	0	0	0	2	36	0	0	2
MEAN		26.40	15.60	32.60	51.80	16.00	11.20	17.00	0.60	0.40	3.20	40.60	5.60	2.20	1.00
SD		12.85	8.32	7.55	9.02	12.00	8.18	24.95	1.90	1.26	3.91	10.83	9.51	6.96	1.41
SE		4.06	2.63	2.39	2.85	3.79	2.59	7.89	0.60	0.40	1.24	3.43	3.01	2.20	0.45

*Note: TH (Tree Height (cm)); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net); SW (Superficial White); SB (Superficial Black); SY (Superficial Yellow); SWy (Superficial White yellow) HNB (Hartig Net Black); HNW (Hartig Net White); HNBr (Hartig Net Brown); HNS (Hartig Net Soft white); HNBe (Hartig Net Beige); SD (Standard Deviation); SE (Standard Error)

Cranberry Portage '84 Tamarack Site

Treatment	TH	MR	NH	SH	HN	SW	SB	SS	SBR	SO	HNB	HNW	HNS	HNBR	HNCL	HNWW	HNO
ROW	47	58	56	6	38	4	0	0	2	0	2	12	0	32	0	0	0
ROW	45	24	68	22	10	22	2	0	0	0	8	0	0	2	0	0	0
ROW	20	8	90	8	2	8	0	0	0	0	0	0	2	0	0	0	0
ROW	50	0	60	24	16	24	0	0	0	0	2	12	2	0	0	0	0
ROW	50	0	50	10	40	10	0	0	0	0	12	36	0	0	0	0	0
ROW	22	20	34	28	38	20	8	0	0	2	26	20	0	0	0	0	0
ROW	22	4	50	10	40	6	2	0	2	0	22	22	0	0	0	0	0
MEAN	36.57	16.29	58.29	15.43	26.29	13.43	1.71	0.00	0.57	0.29	10.29	14.57	0.57	4.86	0.00	0.00	0.00
SD	14.37	20.67	17.49	8.92	16.39	8.30	2.93	0.00	0.98	0.76	10.29	12.79	0.98	11.99	0.00	0.00	0.00
SE	5.43	7.81	6.61	3.37	6.19	3.14	1.11	0.00	0.37	0.29	3.89	4.83	0.37	4.53	0.00	0.00	0.00
UNSPR	50	66	26	32	42	30	2	0	0	0	6	36	0	0	0	0	0
UNSPR	35	34	34	24	42	18	4	0	4	0	20	22	0	0	0	0	0
UNSPR	40	22	54	20	26	24	2	0	0	0	12	16	0	0	0	0	0
UNSPR	46	40	20	20	60	16	4	0	0	0	18	54	0	0	0	0	0
UNSPR	47	26	34	16	50	12	0	0	4	0	50	14	0	8	0	0	0
UNSPR	38	16	30	0	70	0	0	0	0	0	50	26	0	2	0	0	0
UNSPR	37	20	6	20	74	20	0	0	0	0	68	32	0	4	0	0	0
UNSPR	27	58	20	16	64	14	2	0	0	0	58	6	0	4	0	0	0
UNSPR	27	76	18	14	68	6	4	0	0	0	58	0	2	4	0	0	0
MEAN	38.56	39.78	26.89	18.00	55.11	15.56	2.00	0.00	0.89	0.00	37.78	22.89	0.22	2.44	0.00	0.00	0.00
SD	8.23	21.87	13.49	8.60	16.07	9.04	1.73	0.00	1.76	0.00	23.48	16.47	0.67	2.79	0.00	0.00	0.00
SE	2.74	7.29	4.50	2.87	5.36	3.01	0.58	0.00	0.59	0.00	7.83	5.49	0.22	0.93	0.00	0.00	0.00
FORest	25	12	2	2	96	16	2	0	0	0	80	24	4	2	0	0	0
FORest	37	2	8	2	90	26	4	0	0	0	76	10	0	4	0	0	0
FORest	30	26	14	8	82	8	4	0	2	0	42	26	0	10	0	0	0
FORest	29	2	22	24	54	20	12	0	0	0	12	44	0	0	2	0	0
FORest	37	14	8	0	92	14	2	0	0	0	64	52	0	0	0	0	0
FORest	37	20	22	12	64	10	4	0	0	0	6	52	0	2	0	4	0
FORest	40	2	18	36	36	42	10	0	0	2	6	30	0	0	0	0	2
FORest	40	16	8	8	84	10	2	0	0	0	50	46	0	2	0	0	0
FORest	38	2	18	22	60	14	12	0	0	0	48	14	0	0	0	0	0
FORest	43	14	24	18	58	0	18	2	0	0	38	8	0	12	0	0	0
MEAN	35.60	11.00	14.40	13.20	71.60	16.00	7.00	0.20	0.20	0.20	42.20	30.60	0.40	3.20	0.20	0.40	0.20
SD	5.70	8.65	7.53	11.63	19.91	11.51	5.60	0.63	0.63	0.63	27.27	17.02	1.26	4.34	0.63	1.26	0.63
SE	1.80	2.74	2.38	3.68	6.29	3.64	1.77	0.20	0.20	0.20	8.62	5.38	0.40	1.37	0.20	0.40	0.20

*Note: TH (Tree Height); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net) SW (Superficial White); SB (Superficial Black); SS (Superficial Soft white); SBR (Superficial Brown); SO (Superficial Orange); HNB (Hartig Net Black); HNW (Hartig Net White); HNS (Hartig Net Soft white); HNBR (Hartig Net Brown); HNCL (Hartig Net Clear); HNWW (Hartig Net White white); HNO (Hartig Net Orange)

MAFEKING '87 TAMARACK APPENDIX

Mafeking '87 Tamarack Mycorrhizae*

Treatment	E/M	TH	MR	NH	SH	HN	SW	SB	SBr	SWy	HNW	HNB	HNBr	HNWy	HNBe	HNG	HNWa
ROW	M	80	72	12	16	72	6	2	8	0	14	46	10	0	2	0	0
ROW	E	35	66	6	12	82	10	0	2	0	6	64	12	0	0	0	0
ROW	M	50	82	4	16	80	2	6	8	0	14	66	0	0	0	0	0
ROW	M	54	86	26	64	38	16	8	12	0	22	14	2	0	0	0	0
ROW	E	70	82	10	30	60	16	18	2	0	6	52	0	0	2	0	0
ROW	E	53	88	2	46	52	28	4	16	0	2	36	14	0	0	0	0
ROW	E	100	100	20	28	52	4	12	12	0	4	48	0	0	0	0	0
ROW	M	50	90	10	4	86	2	0	2	0	4	82	0	0	0	0	0
ROW	M	85	82	18	12	70	4	4	4	0	4	64	2	0	0	0	0
ROW	E	100	100	8	10	82	2	10	0	0	6	64	0	0	0	12	0
MEAN		67.70	84.80	11.60	23.80	67.40	9.00	6.40	6.60	0.00	8.20	53.60	4.00	0.00	0.40	1.20	0.00
SD		22.71	10.76	7.59	18.70	16.17	8.60	5.72	5.42	0.00	6.36	19.02	5.66	0.00	0.84	3.79	0.00
SE		7.18	3.40	2.40	5.91	5.11	2.72	1.81	1.71	0.00	2.01	6.01	1.79	0.00	0.27	1.20	0.00
FOREST		40	82	56	32	12	22	6	4	0	8	4	0	0	0	0	0
FOREST		45	86	26	34	40	32	0	2	0	36	2	2	0	0	0	0
FOREST		40	44	4	26	70	12	12	4	2	6	64	0	0	0	0	0
FOREST		30	56	26	20	54	14	2	4	0	44	8	2	0	0	0	0
FOREST		60	66	26	46	28	42	2	2	0	12	14	0	2	0	0	0
FOREST		80	54	48	28	24	16	6	6	0	22	2	0	0	0	0	0
FOREST		45	94	34	46	20	38	8	0	0	10	8	0	0	0	0	2
FOREST		60	68	16	50	34	36	6	2	4	4	32	0	0	0	0	0
MEAN		50.00	68.75	29.50	35.25	35.25	26.50	5.25	3.00	0.75	17.75	16.75	0.50	0.25	0.00	0.00	0.25
SD		15.81	17.37	16.62	10.90	19.03	11.89	3.85	1.85	1.49	14.91	21.46	0.93	0.71	0.00	0.00	0.71
SE		5.59	6.14	5.88	3.85	6.73	4.20	1.36	0.65	0.53	5.27	7.59	0.33	0.25	0.00	0.00	0.25

*Note: TH (Tree Height (cm)); MR (Modified Roots); NH (No Hyphae); SH (Superficial Hyphae); HN (Hartig Net) SW (Superficial White); SB (Superficial Black); SBr (Superficial Brown); SWy (Superficial White yellow); HNB (Hartig Net Black); HNW (Hartig Net White); HNBr (Hartig Net Brown); HNWy (Hartig Net White yellow); HNBe (Hartig Net Beige); HNG (Hartig Net Grey); HNWa (Hartig Net White angel); SD (Standard Deviation); SE (Standard Error)

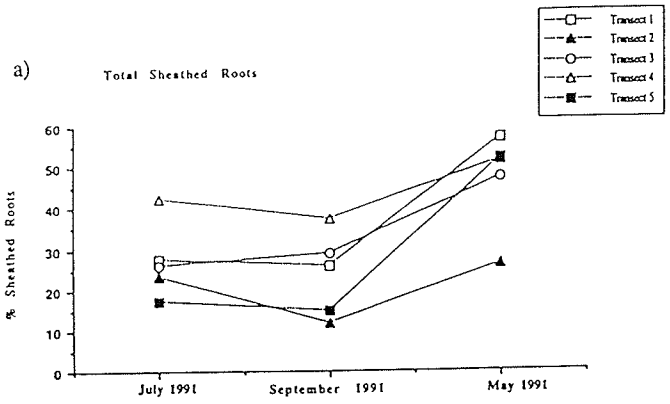
APPENDIX V

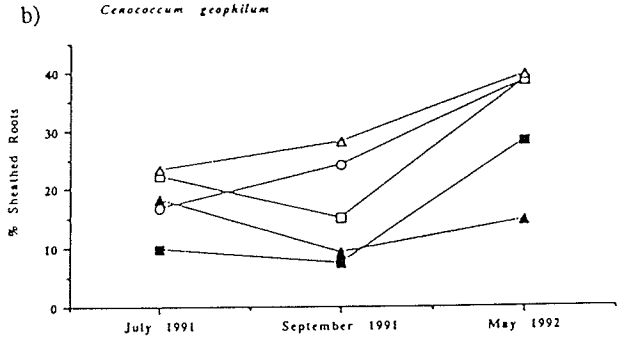
Waterhen Transect Data Illustrated

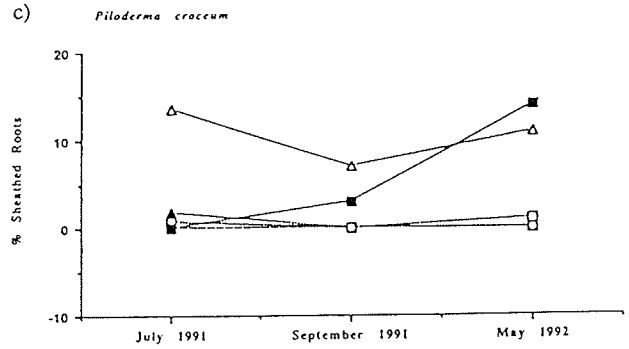
Changes over time after herbicide treatment with *Tordon 101*;

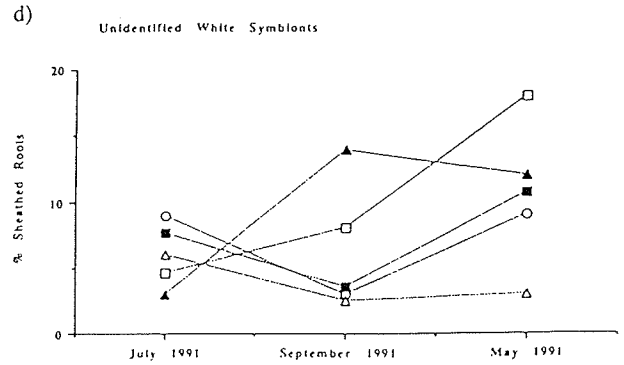
Figures are based on data from Table 5.2a.

(ROW Transects 1 - 5 in July 1991, September 1991 and May 1992 showing a) total sheathed roots; b) *Cenococcum geophilum* infestation; c) *Piloderma croceum* infestation and d) White Mycorrhiza infestation.)


a)
Total Sheathed Roots
Transect 1
Transect 2
Transect 3
Transect 4
Transect 5
% Sheathed Roots
60
50
40
30
20
10
0
July 1991
September 1991
May 1991


b)
Cenococcum geophilum
% Sheathed Roots
40
30
20
10
0
July 1991
September 1991
May 1992


c)
Piloderma croceum
% Sheathed Roots
20
10
0
-10
July 1991
September 1991
May 1992


d)
Unidentified White Symbionts
% Sheathed Roots
20
10
0
July 1991
September 1991
May 1991