DENDROBIOLOGY
2001, vol. 46: 49–58

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Mycorrhizal status of *Pinus sylvestris* L. nursery stock in Poland as influenced by nitrogen fertilization

Abstract: Indigenous mycorrhizal colonisation of one (1/0) and two (2/0) year old Scots pine (*Pinus sylvestris* L.) seedlings from forest nurseries situated in the north-west part of Poland was investigated. Seedlings were fertilized after a schedule designed to satisfy their requirements which resulted from soil analysis of each nursery. In autumn needle nitrogen concentration and mycorrhizal status were estimated. As a rule seedlings 1/0 obtained high doses of fertilizers, and their needle nitrogen concentration highly exceeded the recommended optimal level above which mycorrhiza formation is greatly restricted. Highly negative correlation was found between the nitrogen status of foliage and mycorrhizal quantitative and qualitative colonisation estimated in the abundance class of 0–5. When internal nitrogen level was low, several ectomycorrhizal morphotypes were found on roots of tested plants. Excessive nitrogen fertilization decreased root ramification pattern and along with increased pH promoted ectendomycorrhizal symbiosis. Two-year-old seedlings (2/0) were characterised by significantly lower nitrogen concentration in the needles which resulted in much higher ectomycorrhizal colonisation. Ectendomycorrhizal symbiosis in the case of 2/0 seedlings was scarce. The results indicate that natural colonisation in nurseries is dependent on the soil management practices, especially nitrogen fertilization. Optimalization of nitrogen fertilization may intensify ectomycorrhizal colonisation of the nursery stock from indigenous fungal species and improve the growth of Scots pine seedlings in bare-root nurseries and plantations.

Additional key words: ectomycorrhiza, ectendomycorrhiza, morphotypes

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Introduction

Most of the tree species forming boreal and temperate forest ecosystems live in symbiosis with ectomycorrhizal (ECM) fungi. Trees benefit from the activities of these fungi in nutrient exploration and uptake from the soil (Smith and Read 1997), and increased protection against pathogens (Marx 1973; Duchesne et al. 1987), drought (Boyle and Hellenbrand 1991), and temperature extremes and metal toxicity (Godbold et al. 1998). For nursery seedlings vigorous and differentiated mycorrhiza formation is of exceptional importance because it significantly improves nursery stock quality and subsequent growth after outplanting. However, mycorrhizas are often deficient in modern bare-root nurseries especially in those where soil fumigation, fungicides and fertilization is a routine practice (Le Tacon et al. 1997). It is generally accepted that nitrogen fertilization is among the most important limiting factors in mycorrhiza formation (Björkman 1949; Mikola 1973; Rudawska 1985; Termorshuizen and Ket 1991). In nursery management, substrate fertility is generally maintained by following a fertilization schedule that allows the production of a precise seedling biomass per unit surface area without taking into account specific mycorrhizal requirements. Finally crop failure has often been associated with poor or lack of mycorrhiza in several nurseries in Poland. A recommendation to care for the condition of mycorrhiza to such an extent that seedlings produced in our nurseries are characterised by a high level of ECM symbiosis is included in the guidelines concerning environmental transformation of forest management (Gorzelak 1998a, b).

In this paper we describe the mycorrhizal status of Scots pine seedlings from several bare-root nurseries situated in north-west part of Poland. This study is a part of a larger survey examining the distribution and diversity of mycorrhizal morphotypes of different nursery grown tree seedlings in dependence on soil condition and nursery practices. The objectives of this part of the study were (*i*) to classify mycorrhizal morphotypes on one- and two-year-old *Pinus sylvestris* seedlings, (*ii*) to distinguish between ECM and ectendomycorrhizal (EECM) colonisation, and (iii) to assess needle nitrogen status of tested seedlings and find correlation with ECM and/or EECM formation.

Material and methods

Nurseries sampled

During the following three years (1995, 1996, 1997) one-year-old (1/0) and two-year-old (1/1 or 2/0) Scots pine seedlings were obtained from the state forest nurseries belonging to Forest Districts

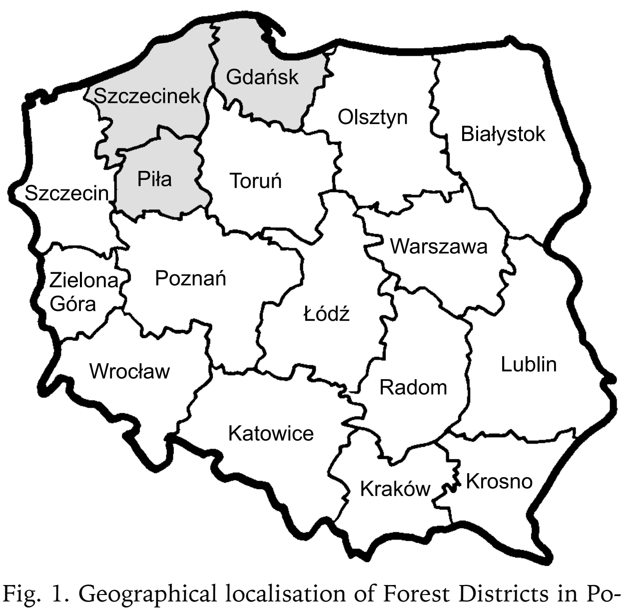

Fig. 1. Geographical localisation of Forest Districts in Poland. The hatched area indicates locations of nurseries in which mycorrhizal surveys were conducted on 1-year-old and 2-year-old *Pinus sylvestris* seedlings

situated in the north-west part of Poland (Piła, Szczecinek and Gdańsk) (Fig. 1). They are all rather large provincial nurseries which range in size from 4 to 10 ha. Standard nursery beds with *P. sylvestris* seedlings were all precision seeded by machine. The soil in most of the nurseries was a fine sandy loam with poorly developed horizons and very little organic matter. Seedlings were fertilized after a schedule designed to satisfy their requirements which resulted from soil analysis of each nursery. Details of rearing, i.e. fertilization regimes, fungicide applications, watering etc. are not presented, however they are available in each nursery. Although this information might have been useful, the objective was to determine the symbiotic status of commercial planting stock, not the causes of the condition. Plant materials were lifted between late August and the end of October. Each sample was composed of 10–15 seedlings. Several replicates were analysed depending on the nursery production and size of nursery beds.

Identification of mycorrhizal associations

Plants with their roots attached were removed from the nursery together with surrounding soil, placed in plastic bags, transported to the laboratory and stored in a cold room (4°C) until use. Prior to examination, the root samples were soaked in water at room temperature, then washed thoroughly on a sieve under a stream of cold water and excised from the main root. The final separation and evaluation of roots were conducted under a dissecting microscope at 10–60× magnification. ECM morphotypes were identified by the absence of root hairs, more or less swollen apex, the presence of a mantle (colour, shape and surface texture), external hyphae, mycelial strands and type of ramification. Occasionally hand sections were made of young monopodial tips to verify the mantle thickness and the presence of a Hartig net. When on the basis of morphological traits the occurrence of EECM was suspected, hand sections were made, and after staining with 0.05% trypan blue (Aldrich Chem. Co.) the presence of hyphae inside cortical cells were verified under an optical microscope (400×). Mycorrhizal tips were categorised into morphotypes based mainly on the booklet of Ingleby et al. (1990) describing ectomycorrhizas commonly encountered on young trees, mostly in nurseries. Other descriptions were also used (Agerer 1987–95; Bradbury 1998; Danielson and Visser 1989; Mohan et al. 1993a, b, c; Ursic and Peterson 1997).

Estimation of mycorrhizal status

The major criterion of the present study was a distinction between ECM and EECM colonisation. Mycorrhizas were not precisely quantified but six abundance classes were distinguished based on visual (macroscopic and microscopic) estimates:

0 Lack of any mycorrhizae; numerous root hairs present on roots.
1 Less than 20% of the root system covered by EECM, numerous root hairs present on roots.
2 About 50% of the root system involved in mycorrhizal symbiosis; domination of EECM, sporadic ECM.
3 More than 50% of the root system involved in mycorrhizal symbiosis; domination of ECM, sporadic EECM.
4 The whole root system mycorrhizal; domination of ectomycorrhizas, about 10% receding EECM.
5 The whole root system mycorrhizal; domination of ECM in the corralloid and tuberculate form, only few ageing EECM.

Nitrogen analyses

At harvest needles of tested seedlings were washed and oven-dried at 80°C. The total nitrogen concentration was determined by the micro-Kjeldahl method.

Results and discussion

The importance of ECM formation for the healthy development and successful transplanting of nursery grown *Pinus* spp. seedlings has been shown in several studies (e.g. Laiho and Mikola 1964; Trappe 1977; Kropp and Langlois 1990). In Polish bare-root nurseries Scots pine seedlings ordinarily become mycorrhizal during the first year of growth. In well run nurseries abundant ECM symbiosis is already present in June, several weeks after sowing (Rudawska, unpublished data). In several nurseries however, mycorrhizal status of Scots pine seedlings at the end of the first growing season is poor and colonisation by EECM fungi is often more widespread than ECM (Fig. 2, Tab. 2).

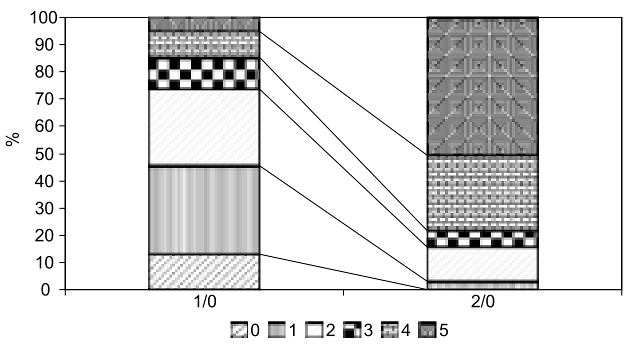

Fig. 2. Ectendomycorrhizal and ectomycorrhizal status of 1-year-old (1/0) and 2-year- old (2/0) *Pinus sylvestris* seedlings from tested nurseries (expressed as percent of samples in which each abundance class occurred). Mycorrhizas estimated in abundance classes 0–5; details of the abundance classes are under the heading 'Estimation of mycorrhizal status' in Material and methods section

One of the most common causes of lack of mycorrhizal symbiosis or predominance of EECM associations on seedlings of conifers in bare-root nurseries is excessive soil nitrogen (N) content, which is reflected in the level of this element in the seedling needles. The nutrient content of needles is directly proportional to the amount of applied nutrient (Anttila and Lähde 1977). Our results clearly showed that Scots pine nursery stock in the first growing season were obtaining excessive doses of nitrogen fertilization, much above the range recommended for plants of this age class (Fig. 3A). This range for 1-year-old Scots pine seedlings is 1.5–2.0% N in the needles (Walendzik and Szołtyk 1993). After one growing season only 25% of the analysed samples fulfilled recommended norms and 75% of the remaining plants were above the norm, reaching up to 3.22% N (Fig. 3A). So high needle N concentration in 1-year-old seedlings results from excessive provision of the soil with this crucial element, which is caused by application of undue doses of N fertilizers. This is reflected by highly restricted root ramification patterns, limited numbers of short roots and, in the absence or marked reduction of mycorrhizal frequency, characterised by the presence of specific

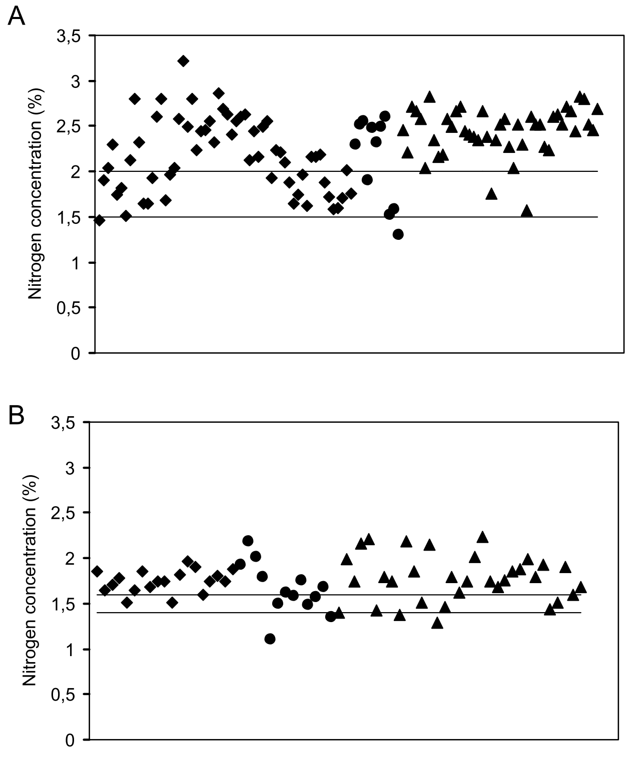

Fig. 3. Needle nitrogen content of 1-year-old (A) and 2-year-old (B) *Pinus sylvestris* seedlings collected in 1995–1997 in nurseries belonging to the State Forest Districts of in Piła (♦), Gdańsk (•) and Szczecinek (▲). Each point represents one sample composed of 10–15 seedlings. The range of the recommended values (1.5–2.0 %) as given by Walendzik and Szołtyk (1993) is indicated

Table 1. Morphological characteristics of the main ectendomycorrhizal (EECM) and ectomycorrhizal (ECM) types (> 5% relative abundance in any one year of sampling) encountered on the roots of 1-year-old and 2-year-old *Pinus sylvestris* seedlings from tested nurseries

EECM or ECM morphotype	Description
EECM I	thin, fawn when young changing to dark brick and brown, with a pale tip, fairly straight and infrequently dichotomously branched, smooth, discontinuous mantle reticulate and shiny, rare extramatrical hyphae (EMH), strands absent, ectendomycorrhizal character – ***Humaria***-like
EECM II	pale straw when young changing darker brown, with white tip, thin and fairly straight and rather unbranched, smooth mantle with EMH extending far from the mantle surface, strands absent, ectendomycorrhizal character – ***Tricharina***-like
MRA	pallid to black, subfloccose, simple and very unfrequently branched, abundant black hyphae loosly surround the base of the mycorrhiza – ***Mycelium radicis atrovirens***-like
ECM I	pale yellowish-brown when young to dark brown when old, dichotomously (bipodial) branched, but also mono-, tri- and tetrapodial, fairly long, mantle smooth with loose, straight EMH over the whole surface, undifferentiated, loselely formed strands often attached to the mantle – ***Thelephora***-like
ECM II	white when young to orange and greyish-brown when old with opaque milk-white lustre, mostly dichotomous but also mono-, tri- and tetrapodial, loose hyaline EMH on the surface of the mantle, strands absent – ***Laccaria***-like
ECM III	light brown covered by abundant white mycelium, dichotomously branched in the early stages and corraloid to tuberculate (clusters) at maturity, sparse ECM, loose white strands – ***Suillus***-like I
ECM IV	light pink or white gelatinous, thick, dichotomous when young, corralloid, fan-shape when older, white abundant EMH, whitish-pink abundant strands – ***Suillus***-like II
ECM V	whitish to buff, short and stubby corraloid branching, mantle smooth but not compact with loose EMH with soil particles on the surface – ***Inocybe***-like
ECM VI	brownish-yelow when young and light brown when old, highly dichotomously branched till complex coralloid forms, mantle surface pubescent with dark-brown EMH, abundant brownish-yellow strands (rhizomorphs), long, rope-like, thick – ***Rhizopogon***-like
ECM VII	yellow to orange, darkening to brown, mycorrhizas fat and dichotomising, significantly fatter than supporting NM roots, mantle smooth and compact covered by straight bristle-like cystidia. Neither EMH nor strands were observed – ***Tuber***-like
ECM VIII	light brown/orange unbranched or infrequently dichotomously branched, dense hyaline to silver-white EMH surrounding the mantle, often bright white spots on the surface, strands absent – ***Hebeloma***-like
ECM IX	black, mantle angular, stellate arrangement, with smooth, stiff hyphae radiating from mantle – ***Cenococcum geophilum*** type
NM	non-mycorrhiza; pale colour, prominent hairs, no fungal mantle and no Hartig net present

mycorrhizas adapted to high doses of nitrogen, i.e. EECM symbiosis (Fig. 2). EECM encountered on roots of Scots pine seedlings in tested nurseries are described in Table 1. Two distinctive EECM morphotypes were found; *Humaria*-like, which dominated in tested nurseries and the much more rare *Tricharina*-like (Ingleby et al. 1990). Both EECM morphotypes were formed by mycelia belonging to a group previously termed 'E-strain' fungi. They differ morphologically from ECM by their thin and elongated appearance. Their mantles were usually scanty or even absent. Also their Hartig net was usually poorly developed. However, microscopic analysis revealed the presence of hyphae inside many cortical cells of the roots. Sometimes EECM were accompanied by ECM (usually *Thelephora* type) but frequently they were the only form of mycorrhizal symbiosis on the analysed 1/0 seedlings (Tab. 2). EECM were most abundant when, apart from excessive N fertilization, soil pH was higher than 6. In several studied nurseries where abundant EECM was noticed, soil pH was higher than 6 and sometimes exceeded 7 (data not presented). As a result, EECM associations in these seedlings were frequent and even predominated over ECM. Similar observations from fertilized forest nurseries were done by Laiho (1965), Mikola (1988) and Lehto (1989) in Finland, and Pachlewski (1983) in Poland. The dynamics that determine whether a *Pinus* seedling will develop ECM or EECM are still unclear. In studies of ammonium assimilation enzymes from several EECM and ECM fungi Rudawska et al. (1994) indicated that EECM fungi (strains MrgX) are better adapted than other ECM symbionts to high nitrogen levels in the soil by their high glutamate dehydrogenase (GDH) activity. Their symbiotic potential expressed by the activity of enzymes synthesising IAA, an important hormone inducing mycorrhiza formation, was comparable with other ECM fungi (Rudawska 1992). Besides high fertility and high pH levels, high water availability has also been qualitatively correlated to the occurrence of EECM (Wilcox et al. 1983; Danielson et al. 1984). Watering is a very common practise in all nurseries in Poland and is probably one of the reasons for increasing population of EECM on bare-root seedlings.

Table 2. Distribution of different mycorrhizal types (> 5% relative abundance in any one year of sampling) encountered on the roots of 1-year-old *Pinus sylvestris* seedlings from tested nurseries (descriptions of morphotypes as in Table 1)

DISTRICT / Nursery	Morphotypes												
	NM	EECM		MRA	ECM								
		I	II		I	II	III	IV	V	VI	VII	VIII	IX
					PIŁA								
Durowo	–	+	–	–	+	+	–	–	+	–	–	–	–
Kaczory	–	+	+	–	+	–	–	–	+	–	–	–	–
Krucz	+	+	–	–	+	–	–	–	–	–	–	–	–
Krzyż	+	+	–	–	+	+	+	–	–	–	–	–	–
Lipka	+	+	–	+	+	–	–	–	+	–	–	+	+
Mirosławiec	+	–	–	–	–	–	–	–	–	–	–	–	–
Potrzebowice	–	+	–	+	+	+	+	–	+	–	–	–	+
Sarbia	+	+	–	–	+	+	–	–	+	–	+	–	–
Wałcz	+	+	–	–	+	+	–	–	–	–	–	–	–
Wronki	+	+	–	+	+	–	–	–	–	–	–	–	–
Zdrojowa G.	+	+	–	–	+	–	–	–	–	–	–	–	–
Złotów	+	+	–	–	+	–	–	–	–	–	–	–	–
					GDAŃSK								
Cewice	–	+	+	–	–	–	–	–	–	–	–	–	–
Kartuzy	–	+	+	–	+	+	–	–	–	–	–	–	–
Kościerzyna	–	+	+	–	–	–	–	–	–	–	–	–	–
Kwidzyń	–	+	+	+	–	–	–	–	–	–	–	–	–
Lębork	+	+	+	–	+	–	–	–	–	–	–	–	–
Lipusz	+	+	–	–	+	+	–	–	–	–	–	–	–
Lubichowo	–	+	+	–	+	–	+	–	+	–	–	–	–
Wejherowo	–	+	+	–	+	–	–	+	–	–	–	–	–
					SZCZECINEK								
Białogard	+	+	–	–	–	–	–	–	–	–	–	–	–
Bobolice	–	+	–	–	+	+	–	–	–	–	–	–	–
Bytów	–	+	–	–	+	+	–	–	–	–	–	–	–
Czaplinek	+	+	+	–	+	–	–	–	+	–	–	+	+
Czarne	–	+	–	–	–	–	–	–	–	–	–	–	–
Człuchów	+	–	–	–	+	–	–	–	–	–	–	–	–
Damnica	+	+	–	–	–	–	–	–	–	–	–	–	–
Drawsko	–	+	–	–	+	+	+	+		–	–	–	–
Dretyń	–	+	+	–	–	–	–	+	–	–	–	–	–
Gościno	–	+	+	–	–	–	–	–	–	–	+	–	–
Kalisz Pom.	–	+	–	–	–	–	–	–	–	–	–	–	–
Leśny Dwór	+	+	–	–	–	–	–	–	–	–	–	–	–
Miastko	+	–	–	–	+	+	–	–	–	–	–	–	–
Niedźwiady	+	+	–	–	–	+	–	–	–	–	–	–	–
Polanów	–	+	+	–	+	–	–	–	–	–	–	–	–
Połczyn	–	+	–	–	+	–	–	–	–	–	–	–	–
Sławno	+	–	–	–	–	–	–	–	–	–	–	–	–
Świdwin	+	+	–	–	+	+	–	–	–	–	–	–	–
Tychowo	+	+	+	–	–	–	–	–	–	–	–	–	–
Złocieniec	–	+	–	–	+	–	+	–	–	–	–	–	–

Note: + present; – absent

It should be emphasised that EECM symbiosis, so common on 1/0 seedlings in our nurseries, is probably not unfavourable for their growth and health condition. Although we know little of the ecology of EECM fungi or their effects on seedling nutrition, growth and survival, EECM have been shown to be beneficial in some instances (Lo Buglio and Wilcox 1988; Wilcox and Ganmore-Neumann 1974). Some danger of predominance EECM symbiosis on seedlings reared in nurseries results from the fact that they eliminate all other, sometimes more favourable mycorrhizal symbionts. Consequently mass dying of pine seedlings takes place after outplanting into the forest stands which in Poland are usually poor in available nitrogen. Under these new conditions EECM withdraw as they do not find enough nitrogen in the soil. During the time necessary for root colonisation by the indigenous ECM fungi the seedlings are unprotected and vulnerable to root pathogens and adverse abiotic factors (drought, temperature, etc.). Parlade and Alvarez (1993) underlined that forest tree seedlings with multiple mycorrhizas can withstand a wider range of plantation site conditions than plants with only one species of mycorrhizal fungus (EECM or ECM).

Occurrence of EECM symbiosis on pines in forest nurseries was also noticed by other authors both in the temperate zone (i.e. Laiho 1965, 1988; Pachlewski and Pachlewska 1971; Wilcox et al. 1983; Molina and Trappe 1984; Mikola 1988; Letho 1989; Ursic and Peterson 1997) and in the tropics (Mikola 1980). These data indicate that EECM symbiosis is ubiquitous among pine seedlings reared in nurseries, however should not be more widespread than ECM. Only 16% of the studied 1/0 seedlings were characterised by abundant ECM (Fig. 2, Tab. 2). The most common ECM morphotypes observed on seedlings in our tested nurseries are described in Table 1. *Thelephora terrestris* is the best known and probably the most common ectomycorrhizal fungus on pine in forest nurseries in Poland and throughout the world (i.e. Hacskaylo 1965; Marx et al. 1970; Molina and Trappe 1984; Mikola 1989; Danielson and Visser 1990; Mohan et al. 1993; Ursic and Peterson 1997). *Thelephora*-like mycorrhizas were the most common on both 1/0 and 2/0 seedlings (Tab. 3). Other, typical fungi accompanying Scots pine in nurseries are *Mycelium radicis atrovirens* (MRA), *Laccaria laccata*, *Suillus* species, *Inocybe lacera*, *Hebeloma crustuliniforme*, *Rhizopogon* sp., *Tuber*-like and *Cenococcum geophilum*. They are more often present on 2/0 than 1/0 seedlings and *Rhizopogon*-like mycorrhizas were encountered on pines only in the second year of growth in nursery condition (Tabs 3 and 4).

In nearly all the analysed 1/0 seedlings, needle N content exceeded 1.6%, which for some authors is supposed to be the maximum for proper development of ECM on conifer seedlings (Gagnon et al. 1995; Nylund 1988). In our surveys we were finding abundant ECM symbiosis when needle N concentration reached 2.0% and occasionally was even higher. This divergences may be attributed largely to the variation in condition among nurseries (pH, organic matter content) and to the differences in the requirements of different fungi predominating in each nursery. The negative effects of fertilization on the mycorrhizal status of seedlings does not indicate that it is impossible to produce ECM plants in bare-root nurseries. From our data it may be concluded that seedling needle concentration of 1.8–2.0% N would be appropriate to maintain abundant and variable ECM of *P. sylvestris* seedlings in condition of forest nurseries. Nutritional regimes of each nursery should be adjusted and controlled to keep needle nitrogen level of Scots pine seedlings less than 2.0%.

It is characteristic of the analysed seedlings that when they are left in the nursery for the second year without nitrogen fertilization, they develop abundant and desirable ECM associations (Fig. 2, Tabs. 3 and 4). As is seen in Fig. 3B, needle N concentration of 2/0 seedlings is generally much lower than 1/0 seedlings, which is reflected in the different structure of mycorrhizal symbiosis. Up to 80% of the seedlings have abundant and diverse ECM (Fig. 2). The trend line for the correlation between needle N concentration and the qualitative and quantitative mycorrhizal status (in the abundance classes 0–5) on 1/0 and 2/0 seedlings indicates a significant negative correlation between these two factors (Fig. 4). The relationship between mycorrhizal community structure (EECM and ECM) and soil fertility appeared in the experiments of Anttila and Lähde (1977). This is the first presented data of the existence of a relationship based on material from commercial nursery production.

Table 3. Occurrence of ectendomycorrhizal (EECM) and ectomycorrhizal (ECM) types encountered on the roots of 1-year-old and 2-year-old *Pinus sylvestris* seedlings from tested nurseries (expressed as percent of nurseries in which each morphotype occurred)

	Morphotypes												
	NM	EECM		MRA	ECM								
		I	II		I	II	III	IV	V	VI	VII	VIII	IX
1-year-old	53	90	33	10	65	33	12.5	7.5	17.5	0	5	5	7.5
2-year-old	14	62	11	3	65	54	62	48	54	19	16	19	19

Table 4. Distribution of different mycorrhizal types (> 5% relative abundance in any one year of sampling) encountered on the roots of 2-year-old *Pinus sylvestris* seedlings from tested nurseries (descriptions of morphotypes as in Table 1)

DISTRICT/ Nursery	Morphotypes												
	NM	EECM		MRA	ECM								
		I	II		I	II	III	IV	V	VI	VII	VIII	IX
PIŁA													
Jastrowie	–	+	–	–	+	+	+	–	+	–	–	+	–
Kaczory	–	+	–	–	+	–	+	–	–	–	+	–	–
Krzyż	–	–	–	–	–	+	+	–	+	–	+	–	–
Lipka	–	–	–	–	+	+	–	–	+	–	–	+	–
Mirosławiec	–	–	–	–	+	+	–	–	+	–	–	–	–
Sarbia	–	+	–	–	+	+	–	–	–	–	–	–	+
Wałcz	+	+	–	–	+	+	+	–	+	–	–	–	–
Wronki	–	+	–	+	+	+	+	+	+	–	–	–	–
Zdrojowa G.	–	+	–	–	+	–	+	+	+	+	–	–	–
GDAŃSK													
Cewice	–	–	–	–	+	–	+	+	+	–	–	–	–
Gdańsk	–	+	–	–	–	–	+	+	+	–	+	+	–
Kaliska	–	+	+	–	+	–	+	–	–	–	–	–	–
Kolbudy	–	+	–	–	–	+	–	–	–	–	+	–	–
Kościerzyna	–	–	–	–	–	–	+	+	+	–	–	–	–
Lębork	–	–	–	–	–	–	+	–	+	–	–	–	–
Lipusz	–	–	–	–	+	+	+	+	+	–	–	–	–
Starogard Gd.	–	+	–	–	–	–	–	–	–	+	–	–	–
Strzebielino	–	+	–	–	+	–	–	–	–	–	–	–	–
Wejherowo	–	–	–	–	+	–	+	+	+	+	–	–	–
SZCZECINEK													
Czaplinek	–	–	–	–	+	+	–	+	–	+	–	+	–
Czarne	–	+	+	–	+	+	+	+	+	–	+	+	+
Człuchów	+	+	–	–	–	–	–	–	–	–	–	–	–
Damnica	–	+	–	–	+	+	+	+	+	+	–	–	–
Drawsko	–	+	–	–	+	+	+	+	+	–	–	+	+
Dretyń	–	+	+	–	–	–	+	+	–	–	+	–	+
Gościno	–	–	–	–	–	+	+	+	+	–	–	–	–
Kalisz Pom.	–	+	–	–	+	+	–	+	–	–	–	–	+
Leśny Dwór	+	+	–	–	–	+	–	–	–	–	–	–	+
Miastko	–	+	–	–	+	+	–	+	–	–	–	+	–
Niedźwiady	–	–	–	–	+	+	+	+	–	–	–	–	+
Polanów	+	+	+	–	–	–	–	–	–	–	–	–	
Połczyn	–	+	–	–	–	–	+	–	–	+	–	–	–
Sławno	–	+	–	–	+	–	–	–	–	–	–	–	–
Szczecinek	+	+	–	–	+	+	–	–	+	–	–	–	–
Świdwin	–	–	–	–	+	+	+	–	–	–	–	–	–
Tychowo	–	–	–	–	–	–	+	+	+	–	–	–	–
Złocieniec	–	–	–	–	+	–	+	+	+	+	–	+	+

Note: + present; – absent

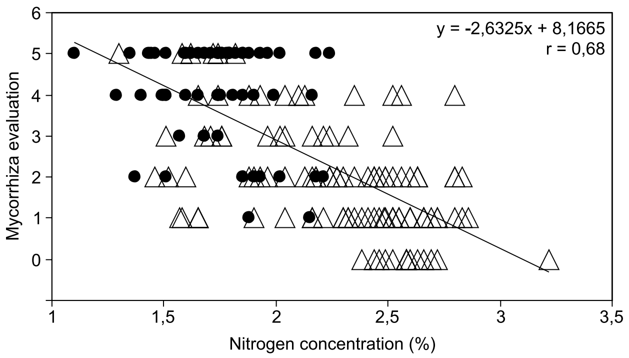

Fig. 4. Relationship between needle nitrogen concentration and ectendomycorrhizal and ectomycorrhizal status of 1-year-old (•) and 2-year-old (∆) *Pinus sylvestris* seedlings from tested nurseries. Mycorrhizas estimated in abundance classes 0–5; details of the abundance classes under the heading 'Estimation of mycorrhizal status' in Material and methods section. Each point represents a pooled sample of 10–15 seedlings

Some deviation from the rule, as visible from figure 4, results from the fact that so complicated and multifactorial a phenomenon as mycorrhiza development is not regulated solely by one factor, i.e. availability of N in the soil.

Since N fertilization is an attractive way to produce big and thrifty seedlings, researchers look for the ways to reach a compromise between fertilization and mycorrhiza. One of the ways is the selection of mycorrhizal symbionts with relatively high tolerance to N fertilization (Väre 1990), followed by introduction of such fungi to nurseries by artificial inoculation. Another solution is frequent application of small fertilizer doses which, unlike the single large doses that are sometimes used in forestry practices, do not have negative effects on the presence and functioning of ECM.

The practices conducted in nurseries should aim at proper care and protection against diseases, pests and weeds, and at the same time at maximum protection and stimulation of the rich community of ECM fungi. Well-developed ECM can significantly improve outplanting performance of such a nursery stock.

Acknowledgements

We thank the Board of State Forest Districts in Piła, Gdańsk and Szczecinek for encouragement to these studies. Thanks are also extended to the forest nursery staffs for the supply of experimental material and their help with fieldwork and in assembling background information. We also acknowledge the helpful comments of two anonymous reviewers. Finally we also thank J. Page for improvement of the English version of the manuscript.

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