Ectomycorrhizae in a Deciduous Forest near a Factory of Chemical Fertilizes

DANUTĖ STANKEVIČIENĖ
Institute of Botany
Žaliųjų ežerų 49, LT-2021 Vilnius, Lithuania

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The influence of industrial emissions upon the formation of ectomycorrhizae in deciduous forests in Lithuania was studied. Abundance of ectomycorrhizal roots (mg of dead + alive ectomycorrhizal roots/g of dry soil) and the number of ectomycorrhizal root tips in 100 cm^3 of soil were counted. Seven forest plots (30x30 m) situated at different distances from the Kėdainiai chemical factory were chosen for investigation. The nearest Juodkiškis forest was at a distance of about 0.7 km, and the farthest Lančiūnava forest – 15 km. The slightest reaction of ectomycorrhizae to pollution was detected in the Lančiūnava forest situated at the largest distance from the chemical factory. Here the total biomass of ectomycorrhizal roots was largest if compared with other investigated forests - 1.03 mg/g dry soil, alive roots – 0.34 mg/g, and the number of ectomycorrhizal root tips was 1000/100 cm^3 of soil (the average of the investigation period). The strongest reaction of ectomycorrhizae to the increased amount of nutrition was determined in the closest-laying Juodkiškis forest (0.7 km). The concentration of inorganic phosphorus up to 1000 mg/kg (d.w.) and 1.0 % of nitrogen almost totally inhibited the formation of ectomycorrhizae in this forest. The lowest amount of alive ectomycorrhizal roots was found in the Vilainiai and Pašiliai forests situated at a distance of 3–5 km from the factory and characterised by the highest concentration of heavy metals in the soil. Zn and As seem to be important agents influencing the formation of ectomycorrhizae in the investigation area.

Key words: ectomycorrhizae, deciduous forest, pollution, Lithuania

Introduction

Ectomycorrhizal fungi are important in the functioning of most temperate forest ecosystems because they mobilize and acquire most nutrients used by trees as well as account for about 20 % of the total energy cycling of forests (Dahlberg *et al.* 1997). Mycorrhizal associations have been recognised to have significant influences on forest ecosystems by enhancing the nutrient uptake of host trees and improving the adaptation of host trees to various environmental conditions (Matsuda and Hijii 1998). Ectomycorrhizal fungi and host trees are ecologically dependent; their survival, growth, and fitness are often predetermined by successful establishment and function of mycorrhizal symbiosis.

Anthropogenic impacts have been observed to alter ectomycorrhizal colonisation and community structure. Over the last several decades the decline of species and sporocarps of ectomycorrhizal fungi in the Netherlands was noted (Arnolds 1991). This process was attributed to increasing deposition of N. A species-specific decrease in ectomycorrhizal sporocarps, a reduction of short roots (Haug 1990) and declining ectomycorrhizal diversity were also attributed to chronic deposition of N and acid (Dighton and Skeffington 1987, Ohtonen *et al.* 1990, Arnolds 1991, Rangel–Castro *et al.* 2002). It appears that ectomycorrhizal development is negatively affected by thick layers of nitrogen-rich litter and humus: litter depth and abundance of ectomycorrhizal sporocarps are negatively correlated; root growth and ectomycorrhizal development might have been favoured by the nutrient-poor conditions (Baar 1997). Heavy metals might also produce negative effect upon the development of ectomycorrhizae; they reduce ectomycorrhizal growth and colonisation (McCreight and Schroeder 1982, Dixon 1988) and might change the structure of ectomycorrhizal community because different fungi species react specifically to heavy metals. Tam (1995) noted high tolerance of *Pisolithus tinctorius* to some metals (Al, Fe, Cu, Zn, Cd, Cr) in comparison to two strains of *Thelephora terrestris* and *Cenococcum geophilum*. Entry et al. (1994) found evidence that ectomycorrhizal seedlings of *Pinus panderosa* and *P. radiata* are able to remove three to five times more of ^{90}Sr from contaminated soil than seedlings without mycorrhizae. Therefore, pollution of the environment, caused by anthropogenic impact, could alter the state and diversity of ectomycorrhizae and ectomycorrhizal fungi along with forest productivity and regeneration (Dighton and Jansen 1991).

The aim of this study was to investigate the influence of anthropogenic pollutants (enlarged amount of nutrients, heavy metals) on the abundance of ectomycorrhizal roots in deciduous forests situated at different distances from the chemical factory. The first product of this chemical enterprise was obtained in 1963. At present, major product of the company is nitrogen phosphorus fertiliser. The main emission products are NO_x, CO, sulphur anhydrite, apatite, fluorine. Hard pollutants emitted from the chimneys make up about 140 t/year (the data provided by the Ministry of Environment of the Republic of Lithuania).

Material and methods

Study site. The study site was located near Kėdainiai city in Central Lithuania (70 m above the sea level). The mean annual precipitation and mean air temperature were 550 mm and 6.4° C. Seven study plots of the size 30x30 m situated at different distances from pollution source were chosen. Care was taken to choose plots with similar vegetation along the gradient of pollution. The study area was occupied by deciduous forest stands. Dominant tree species were *Fraxinus excelsior* L., which is known to form vesicular–arbuscular mycorrhizae, *Populus tremula* L., *Padus avium* Mill., *Corylus avellana* L., which form ectomycorrhizae. The nearest plots Zabieliškis-Šilainėliai (I) and Juodkiškis (II) – were about 3–0.7 km south-east and east of the emission source, respectively, the Vilainiai (III) and Pašiliai (VII) forests – about 3 km north-east and 5 km south-west, Stebuliai (IV) and Berunkiškis (VI) – about 8 km north-east and south-east, and the Lančiūnava (V) forest – about 15 km east of it, respectively.

Sampling and observation of ectomycorrhizae. The investigated forest plots were visited twice a year - at the beginning of May and October during 1999–2001. The state of ectomycorrhizae was determined in soil cores of 4.5 cm in diameter and 15 cm in depth. Soil cores were divided into three soil layers: A – upper layer 0-5 cm, B - middle layer 5-10 cm, C - deeper layer 10–15 cm. Three representative samples (A, B, C) for each research plot were composed of 18-20 randomly taken soil cores. Soil samples were stored at a temperature of 4° C until further ectomycorrhizal investigation. Ectomycorrhizal roots were processed within two weeks after the collection of soil cores. From each representative sample 100 g of the soil were taken for investigation of ectomycorrhizae (another part of the soil was used for chemical analyses). The soil sample was soaked in tap water overnight and the roots gently cleaned under running water using the 0.5 mm sieve. The following criteria were chosen for the evaluation of the ectomycorrhizae state: 1) abundance of ectomycorrhizal roots (amount of dead + alive ectomycorrhizal roots – mg/g dry weight), 2) abundance of alive ectomycorrhizal roots (mg/g), 3) the number of ectomycorrhizal root tips in 100 cm^3 of the soil. Ectomycorrhizal roots were sorted out under the stereoscopic microscope and divided into dead (wrinkled or shrunk, without turgor) and alive. The dead ectomycorrhizal roots were dried at a room temperature and weighed. The number of tips of separate morphological types (viable mycorrhizae) was counted. Then roots of different ectomycorrhizal morphotypes were also dried at room temperature and weighed.

Soil analyses. The concentration of nitrogen and phosphorus was determined photometrically applying photometer "SPEKOL11", the humus content – colorimetrically (Mineev, 1989). Soil pH_{KCL} was measured potentiometrically with glass electrode in a 1.0 M KCl suspension. The concentration of heavy metals – Pb, Cd, Zn, Cu, Cr, Ni and As – in the soil was determined using a Perkin-Elmer Zeeman 3030 atomic absorption spectrophotometer.

Data analysis was carried out employing the methods of statistics (Zar 1999) using the software *Stattistica 4.5.* Pair comparisons were made by a Student's *t*-test (P=0.05)

Results and discussion

Evaluation of the abundance of ectomycorrhizae in different investigation plots performed in 1999 – 2001 revealed the highest amount of ectomycorrhizal roots in the Lančiūnava (V) forest (Table 1, Fig. 1). The lowest amount of these roots was in the Vilainiai (III) forest. The highest amount of alive ectomycorrhizal roots was determined in the Lančiūnava and Berunkiškis forest, while the lowest in Pašiliai and Vilainiai. So, the largest amount of ectomycorrhizal roots was in the forest situated at the largest distance (≈15 km) from the factory. It is noteworthy that the Juodkiškis forest, nearest to the factory, was characterised by high amount of mycorrhizal roots (in 1999 and 2001). However, comparing these two forest plots according to the diversity of morphotypes the differences were noted. The amount of morphotypes in the nearest (Juodkiškis) forest was more than twice lower and morphotypes were darker in colour than in the most distant (Lančiūnava) forest (the data will be soon published). However, some authors (AL Sayegh Petkovšek and Kraigher 1999) claimed that dark types (black or dark brown) could not be ranked among the bioindicators of the pollution of forest soils.

Table 1. Amount of ectomycorrhizal roots in different investigation plots (S – spring, O – autumn)

Forest plot	Content of ectomycorrhizal roots mg/g d.w. (A layer) 1999 S	1999 O	2000 S	2000 O	2001 S	2001 O	mean	Sx
	Alive							
I	0.49	0.014	0.06	0.119	0.13	0.04	0.142	0.11
II	0.48	0.02	0.032	0.003	0.04	0.23	0.134	0.14
III	0.12	0.001	0.244	0.013	0.01	0.06	0.075	0.07
IV	0.19	0.072	0.021	0.256	0.19	0.2	0.155	0.07
V	0.81	0.23	0.074	0.432	0.26	0.26	0.344	0.18
VI	0.2	0.032	0.004	0.607	0.11	0.22	0.196	0.14
VII	0.05	0.016	0.07	0.023	0	0.11	0.045	0.03
	Dead							
I	2.4	0.124	0.28	0.397	0.63	0.09	0.653	0.58
II	1.73	0.36	0.274	0.039	0.68	1	0.681	0.45
III	0.51	0.086	0.487	0.026	0.1	0.19	0.233	0.17
IV	0.95	0.62	0.055	0.393	0.18	0.23	0.404	0.25
V	1.34	0.48	0.265	0.724	0.78	0.52	0.684	0.26
VI	1.96	0.85	0.555	0.402	1.2	0.23	0.866	0.47
VII	0.92	0.46	0.43	0.113	0.15	0.33	0.401	0.21
	Number of tips/100 cm^3 of soil							
I	438	55	244	487	241	93	259	135
II	610	122	162	13	79	426	235	188
III	336	22	183	80	48	135	134	135
IV	506	354	59	1460	834	982	699	392
V	2045	503	188	905	1149	1204	999	467
VI	298	182	30	1331	193	697	455	372
VII	262	33	130	60	0	135	103	72

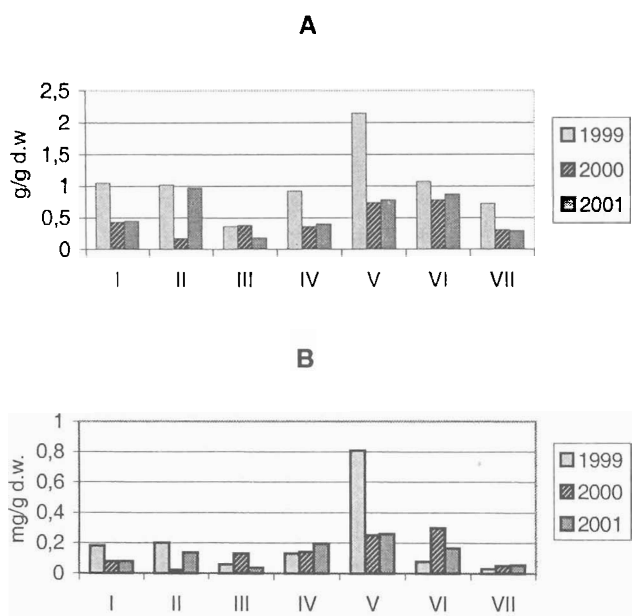

Figure 1. Distribution of ectomycorrhizae (A – total amount: dead+alive; B – alive) in different forests plots in 1999-2001 (average of A, B, C layers in spring and autumn)

The amount of alive mycorrhizal roots varied in the course of investigation years (1999–2001). Alive mycorrhizae in separate forest plots in different years made up from 4 % (Pašiliai, 1999) to 49 % (Stebuliai, 2001) of the total amount of ectomycorrhizae. Median interval of this parameter ranged from 20 to 40 %. The highest amount of mycorrhizal roots was detected in 1999 (average of spring and autumn). This number in 2000 and 2001 was lower and rather similar. Looking for the reasons for this specific quantitative distribution of ectomycorrhizae in different forest plots (I-VII) and years (1999–2001) the chemical composition of soil and climatic conditions were taken into account.

The data on soil chemical composition revealed rather strong fluctuations in 1999-2001 (Table 2). The highest variation was noted in the concentration of phosphorus; its content particularly increased in 2000 (Fig. 2). It was threefold higher than in 1999 and twofold higher than in 2001. The content of nitrogen also varied, but the variation was lower. The concentration of nitrogen in the soil in 2000 was 34 % higher than in 1999, and 7 % higher than in 2001. The dynamics in the variation of humus were similar. This data visibly demonstrates negative correlation between the intensity of ectomycorrhizal formation and surplus input of nutrient resulting from considerable emission ($r = -0.73$ in case of phosphorus and $r = -0.71$ in case of nitrogen). Our data confirm the fact that root growth and ectomycorrhizal development might be favoured by the nutrient-poor conditions of the soil (Baar 1997, Munzenberger *et al.* 1995, Kraigher *et al.* 1995). It was also determined that variation in the nutrient concentration generally reduced the relative growth rate of mycorrhizal plants. Mycorrhizal plants had higher relative growth rate at low nutrient concentration and

Table 2. Chemical composition of soil from different investigation plots in spring (S) and autumn (O) in 2000

Forest plot	Soil layer	N (%) S	N (%) O	P_2O_5 (mg/kg d.w.) S	P_2O_5 O	Humus (%) S	Humus (%) O	pH (KCL) S	pH (KCL) O
I	A	0.425	0.484	72.9	298.1	7.67	7.32	5.05	4.64
	B	0.296	0.466	41.7	346.2	6.15	6.82	4.63	4.35
	C	0.219	0.337	32.5	307.7	4.03	5.36	4.34	4.19
II	A	0.333	1.058	339.6	1288.5	8.58	16.82	4.06	4.35
	B	0.277	0.508	342.1	913.5	6.39	8.27	4.15	4.13
	C	0.177	0.487	283.8	730.8	4.45	5.7	4.37	6.19
III	A	0.513	0.495	101.7	326.9	8.73	7.17	6.38	4.45
	B	0.488	0.442	93.3	317.3	8.45	7.91	6.42	6.16
	C	0.431	0.345	81.7	298.1	7.7	5.74	6.46	6.51
IV	A	0.438	0.484	111.7	259.6	7.32	7.7	6.23	6.02
	B	0.385	0.679	98.8	365.4	5.36	10.23	6.12	6.06
	C	0.35	0.405	101.7	269.2	5.82	5.57	6.17	6.09
V	A	0.502	0.311	58.3	230.8	7.97	6.3	5.72	3.45
	B	0.417	0.321	55	278.8	6.77	5.78	5.39	4.36
	C	0.317	0.245	53.8	240.4	5.18	5.43	5.55	4.35
VI	A	0.298	0.221	30	51.9	6.53	4	5.05	5.12
	B	0.271	0.218	29.2	173.1	5.88	4.05	4.86	5.71
	C	0.227	0.187	26.7	44.2	4.74	3.77	5.04	5.07
VII	A	0.713	0.911	47.9	346.2	8.85	12.5	5.25	5.15
	B	0.658	1.055	42.5	355.8	8.79	15.55	5.26	5.03
	C	0.542	0.8	37.5	326.9	8.42	9.27	5.29	5.16

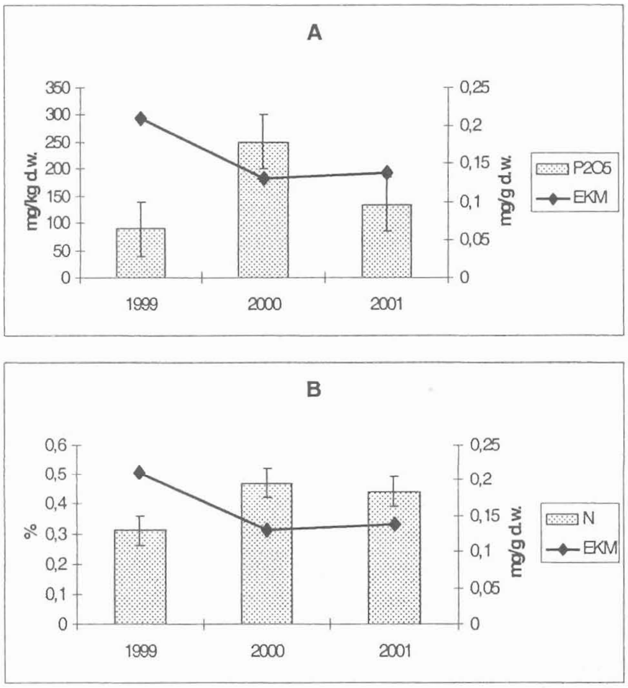

Figure 2. Dynamics of phosphorus (A), nitrogen (B), and alive ectomycorrhizae (EKM) (mg/g d.w.) on the investigation area (average of different plots) in 1999–2001

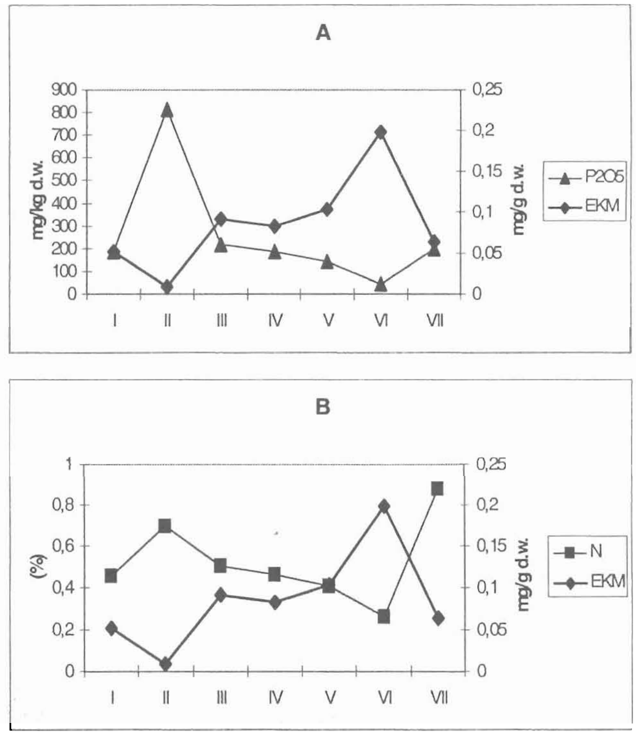

Figure 3. Changes in the concentration of nutrients (phosphorus - P_2O_5 mg/kg d.w., nitrogen – N %) and abundance of ectomycorrhizae (EKM mg/g) in different investigation plots in 2000 (average of spring and autumn in A,B,C soil layers)

non-mycorrhizal – at high nutrient concentration (Aikio, Ruotsalainen 2002)

Analysis of the soil chemical composition in the samples from separate investigation plots asserted that the chemical industry produced the strongest impact upon the closest-laying Juodkiškis forest. Comparing the concentration of nutrients in soil samples taken in the spring (May) and autumn (October) of 2000, evident seasonal differences were noted (especially for phosphorus – $t = 3.95$; meanwhile, reliable seasonal differences were not observed in 2001 and 1999). The amount of mobile phosphorus in Juodkiškis soil increased fourfold and that of N – threefold in autumn (Table 2). The reason for this increase could be the accident, which took place in the factory in May 2000 (the information was in local press – "Lietuvos rytas", June 21, 2000). Therefore, this high nutrient concentration in soil (from 730 mg P_2O_5/kg dry matter in "C" level of soil to 1288 mg/kg in "A" level, and N – 0.48 % and 1.06 % accordingly) almost totally inhibited the ectomycorrhizal formation in this forest (Fig. 3). The lowest concentration of nutrient was observed in the Berunkiškis forest (VI), and the amount of ectomycorrhizal roots was highest in this investigation plot. Application of nitrogen fertilisers is known to cause declines in the diversity and/or abundance of ectomycorrhizal fungal species (Miller and Lodge 1987). Ectomycorrhizal fungi are to confer special advantages to trees in the uptake of nitrogen from organic residues in the environment where the availability or uptake of nutrients is limited (Read 1991); it explains why chronic additions of nitrogen from air pollutants are associated with the decline in ectomycorrhizal fungi and their associated host trees.

The content of nutrients was highest in the nearest Juodkiškis forest during the whole investigation period (1999–2001). But in 1999 and 2001 the number and biomass of ectomycorrhizal root tips in this forest was not smallest (Table 1, Fig.1). The lowest content of ectomycorrhizal roots was determined in the Pašiliai (VII) and Vilainiai (III) forests in 1999 and 2001. It seems to be other agent additionally influencing ectomycorrhizal formation. Therefore, the distribution of heavy metals in separate forests was analysed (Table 3). The soil from Pašiliai forest bore the highest concentration of heavy metals. This forest was characterised by much higher Zn and As concentration comparing with other investigation plots. The concentration of the above-mentioned metals was rather high

Table 3. Concentration of heavy metals (μg/g d.w.) in investigation plots (1999 and 2001)

Plot	Pb		Cd		Ni		Cr		As		Cu		Zn	
	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001
I	8	30.6	0.04	0.13	8.2	6	10.37	13	1.2	1.25	2.83	4.95	19.8	20
II	8.87	12.8	0.05	0.25	4.4	7.6	0.9	10	0.9	0.9	2.1	9.75	19.8	20
III	15	12.5	0.07	0.17	10.5	6.6	12.7	15	1.8	1.7	3.3	5.65	37.4	22
IV	10.67	11.4	0.07	0.12	8.8	5.2	9.9	12	1.3	1.1	2.1	4.65	33	21
V	13.63	9.6	0.11	0.17	8.9	6.8	12.13	13	1.1	1.4	2.63	5.2	26.4	19
VI	13.9	9.1	0.14	0.07	15.8	5.5	9.8	12	1.3	0.95	2.94	3.6	20.1	16
VII	13.13	13.8	0.07	0.25	17.6	12.1	19.53	21	1.8	1.2	3.63	9.25	57.2	25

in the Vilainiai forest as well. The concentration of As in this investigation plot was highest. Meanwhile the content of As and some other metals (Ni, Cr, Pb) was lowest in 1999 and 2001 in the Juodkiškis forest. Therefore, an assumption can be made that heavy metals (as well as high concentration of nutrients), especially As and Zn, strongly impinged the process of ectomycorrhizal formation. The suppressed ability of symbionts to form ectomycorrhizal structures due to heavy metals was noted by other authors. (Dixon 1988, Jones and Hutchinson 1986). On the other hand, ectomycorrhizal colonisation reduced metal toxicity towards the host seedlings. The ectomycorrhiza *Rhizopogon roseolus+Pinus sylvestris* was shown accumulating Cd and Al in the fungal mantel thus decreasing these elements gradually along the Hartig net towards the inside of the root - suggesting a filtering effect (Turnau *et al.* 1996).

Comparing the abundance of ectomycorrhizae in soil samples taken in spring and autumn no strong differences were determined. The content of ectomycorrhizal roots in 2000 and 2001 was higher in autumn; meanwhile, in 1999 it was higher in spring. Probably different factors, e.g., climatic ones influenced this distribution as well. Evaluation of the dynamics of climatic factors (precipitation and temperature data provided by Kėdainiai weather-station) during the investigation period revealed that the driest vegetation season (May–October) was in 1999 when the abundance of ectomycorrhizae in autumn samples was lowest. Meanwhile the amount of precipitation in winter season (November–April) of the above-mentioned year was highest and amount of ectomycorrhizal roots was highest as well (Fig. 4). The years 2000 and 2001 were similar regarding the criteria of evaluation (Fig. 5). Positive correlation was determined between the amount of precipitation and abundance of ectomycorrhizae over the investigation time (r = 0.81). Baar et al. (2002) found that the number of ectomycorrhizal root tips of *Alnus glutinosa* in a desiccated forest along a stream was generally smaller than in an undisturbed wet Alder carr forest on waterlogged soil in the same area. Rastin *et al.* (1990) during the investi-

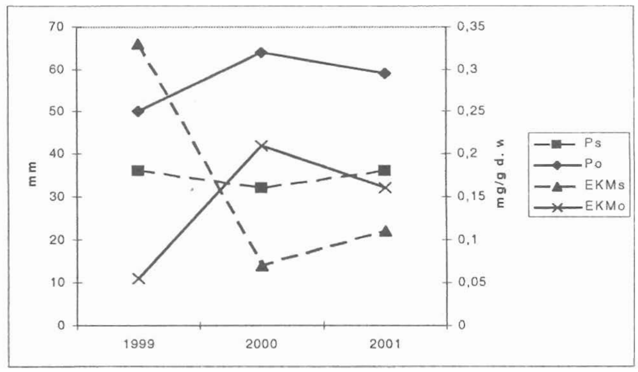

Figure 4. Seasonal dynamics of amount of ectomycorrhizae (ECMs – spring amount, EKMo – autumn amount) and precipitation (Ps – spring precipitation, Po – autumn precipitation) on investigation area in 1999-2001

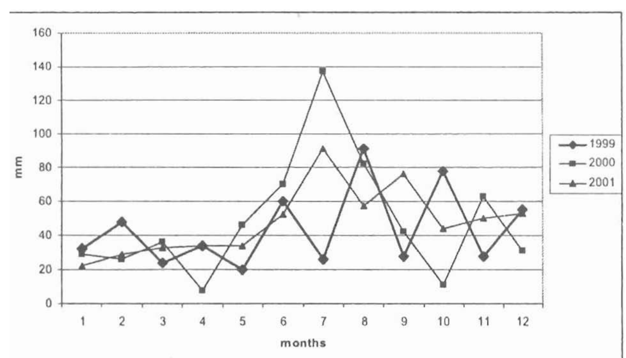

Figure 5. Dynamics of precipitation in 1999 – 2001

gations on seasonal fluctuation of some soil factors on the upper and lower slope of a spruce forest showed that the maximum values of mycorrhizal root tips were reached in the moulder humus layer towards the end of winter (February and March) and at the beginning of summer (July). In the underlying organic layer the peaks occurred during spring (April–May) and autumn (October–November). It was concluded that differences in the seasonal courses of soil biological factors occurred due to varying environmental conditions. The nutrient supply, soil moisture, and physical conditions of the soil have a strong interdependence and produce complex influence upon the processes in the soil. The issue of the possibility of ectomycorrhizal fungi to improve the water relations of trees are considered. Smith and Read (1997) reported that colonisation by *Cenococcum geophilum* increased the drought resistance of *Tilia cordata*. In the studies on *Pinus ponderosa* it was determined that mycorrhizal colonisation improved the survival of plants after short periods of exposure to drought but had little effect over longer periods. If rhizomorphs of *Suillus bovinus*, connecting mycorrhizal seedlings of *Pinus sylvestris* to moist soil, were cut, transpiration declined markedly within minutes. It demonstrates that plants are dependent on symbionts under the drought conditions.

The abundance of ectomycorrhizae varied in separate soil levels (A, B, C). The highest concentration of ectomycorrhizae about 50-70 % was in level "A" (up to 5 cm) in level "B" ≈ 20 % (5–10 cm), and the lowest amount of ectomycorrhizal roots was found in level "C". It demonstrates that ectomycorrhizae form in upper soil layers up to 10 cm. This study confirms the data obtained by other authors. Gardes and Bruns (1996) reported that most of the ectomycorrhizae were located at the interface of organic matter and mineral soil. Up to 66 % of mycorrhizae associated with *Pinus sylvestris* were spread in humus layer up to 5 cm depth (Rudawska 1997).

Conclusions

Current investigation has revealed different influence of industrial emissions upon the formation of ectomycorrhizae along the pollution gradient. The lowest reaction of ectomycorrhizae to pollution was determined in the Lančiūnava forest situated at the largest distance from the chemical factory – 15 km. The strongest reaction of ectomycorrhizae to the increased amount of nutrient was determined in the closest-laying Juodkiškis forests – 0.7 km. Concentration of up to 1000 mg/kg d. w. of inorganic phosphorus and 1.0 % of nitrogen almost totally inhibited ectomycorrhizal formation in this forest. The lowest amount of alive ectomycorrhizal roots was found in the Vilainiai and Pašiliai forests situated at a distance of 3–5 km from the factory and characterized by the highest concentration of heavy metals. Zn and As seems to be important agents influencing the formation of ectomycorrhizae in the investigation area. There is a positive correlation between the abundance of ectomycorrhizal roots in the soil and amount of precipitation.

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СОСТОЯНИЕ ЭКТОМИКОРИЗЫ В ЛИСТВЕННОМ ЛЕСУ ВБЛИЗИ ЗАВОДА ХИМИЧЕСКИХ УДОБРЕНИЙ

Д. Станкявичене

Резюме

Исследовалось влияние химической промышленности на формирование эктомикоризы в лиственном лесу в Литве. Проводилось исследование семи лесных участков (30x30 м) расположенных на различном расстоянии от Кедайняйского химического завода. Ближайший лес Juodkiškis расположен на расстоянии около 0,7 км, а наиболее отдаленный лес Lančiūnava – около 15 км. Наименьшая реакция эктомикоризы была установлена в лесу Lančiūnava, который расположен на самом дальнем расстоянии от химического завода. Общая биомасса эктомикоризных корешков (живая + мертвая микориза) в этом лесу была наибольшая по сравнению с другими исследованными участками – 1,03 мг/г (сухой вес), живых эктомикоризных корешков – 0,34 мг/г и число эктомикоризных корневых окончаний было примерно 1000/100 см^3. Наиболее выраженная реакция эктомикоризы на повышенное количество питательных веществ была установлена в ближайшем лесу Juodkiškis (0,7 км). Концентрация неорганического фосфора около 1000 мг/кг сухой почвы и азота около 1% почти полностью подавляли образование эктомикоризы в упомянутом лесу. Наименьшее количество живых эктомикоризных корней было найдено в лесах Vilainiai и Pašiliai, расположенных на расстоянии 3 – 5 км от завода, выделяющихся наибольшей концентрацией тяжелых металлов. Среди исследованных металлов, Zn и As оказались основными факторами, влияющими на формирование эктомикоризы в выше упомянутых лесах.

Ключевые слова: эктомикориза, лиственный лес, загрязнение