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Importance of *Cytospora* damage in relation to health state of birch trees in urban greenery – demonstrated by example of the Nitra town

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Abstract

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Over the years 2005–2007, the health state of *Betula* species in urban environment of Slovakia was evaluated with prime emphasis on occurrence and harmfulness of *Cytospora betulicola* Fautr. on example of the Nitra town. Damage degree to selected birch trees in five different greenery types of usage/location (street plantings, plantings in residential areas – neighbourhood plantings, main-roadside plantings, park plantings, special-purpose greenery) was determined in relation to incidence of the *Cytospora* fungus, wood destroying fungi and unknown factors. The one-way ANOVA did not confirm generally a significant influence of greenery type of usage/location on the damage degree of birch trees. Significant differences in the damage degree values were confirmed between some greenery types by using t-test. *Cytospora* fungus and wood destroying fungi significantly influenced birch health state decrease. Results of multifactorial variance analysis have confirmed a significant influence of two factors, *Cytospora betulicola* and wood destroying fungi on increase of damage degree.

Key words

Betula, *Cytospora* cankers, damage degree, wood-decay fungi

Introduction

Cytospora canker, caused by fungi of *Cytospora* genus, is a worldwide problem and affects more than 70 species of woody shrubs and trees, including aspen, cottonwood, poplar, spruce, willow, ash, maple, elm, cherry, peach, plum, apple and birch (Agrios, 1997). *Cytospora* fungi are widely distributed throughout the range of their hosts in many parts of Europe (Ginns, 1986; Chapela, 1989; Sinclair et al., 1987). Several studies have confirmed *Cytospora* occurrence on a wide spectrum of host woody plants in horticultural plantings and urban environment (Kochman, 1981; Bennell and Millar, 1984).

Six genera (*Betula, Corylus*, *Carpinus*, *Alnus*, *Ostrya*, *Ostryopsis*) and more than 150 species of deciduous trees and shrubs of *Betulaceae* family grow in the nature. Species of the *Betula* genus belong to trees often grown as markedly decorative woody plants in urban plantings. Several fungi cause canker diseases on birch, infect and kill sapwood and cause sunken dead areas in the bark of trunks and larger branches. Infection causes dieback of twigs and branches, with small black fungal structures embedded in the dead outer bark. Disease occurs on trunks, branches and twigs, forming elongate cankers, regular or irregular in outline, generally with well-defined borders.

Some recent studies have demonstrated damage caused by *Cytospora* pathogens to many birch species (Gregorová et al., 1995; Barengo et al., 2000). Based on the recent studies, some *Cytospora* species are host specific and will not spread to other tree species (Chen, 2002). Since the last years, an increasing number of birch trees in Slovakia have been damaged by *Cytospora* (Juhásová et al., 2005). Juhásová (2004) reported the species *Cytospora betulicola* Fautr. on *Betula* sp. that caused trunk and branche necrosis and withering of branches in tree crowns.

Many factors can influence health of trees, impair their aesthetic value, or cause even death: environmental stresses, location problems, animal injury, infectious diseases and insect infestations. In many cases, more than one factor may be involved. A correct diagnosis of the problem is the first important step for saving unhealthy trees as a valuable part of the environment. In individual cases, the specific causes of birch dieback are often difficult to determine. Several environmental conditions are known to cause the dieback (Allen et al., 1996).

Results of many studies on tree health state in Slovakia indicate that premature death, leaf spots, yellowing and falling leaves and other damage can be caused by higher concentrations of liquid and solid immisions, salting along roads, poorly areated or unaerated soil or by influence of parasitic fungi, viruses and bacteria (Juhásová and Gáper, 1986; Juhásová, 1997; Juhásová et al., 2003). According to Juhásová et al. (2004), Juhásová and Ivanová (2001), the present health state of woody plants in urban environment is strongly disturbed and the stressed trees are less able to resist insect and disease attack.

Parasitic fungi are one of the very important factors that cause disturbances in the vital processes of plants. Such fungal diseases are manifested as variously spotted leaves and tumour malformations on trunks and branches, often followed by drying of whole tree crowns or even whole affected trees. Important damage caused by *Cytospora* fungi to woody plant species in urban settings was noticed in Slovakia by Juhásová and Ivanová (2003).

The present work was aimed at evaluation of health state of *Betula* sp. in urban plantings on the basis of determination of damage degree to birch trees with the main respect to damage caused by the parasitic fungus *Cytospora betulicola* Fautr. that presents an important problem for withering and dieback of birches in Slovakia. This study wants to extend knowledge on *Cytospora* pathogenicity on the basis of phytopathological evaluation of the investigated tree species.

Material and methods

Field evaluation

Over the years 2005–2007, the health state of *Betula* sp. div. with regard to *Cytospora* incidence was evaluated in urban plantings of Nitra. The various locations of evaluated trees were selected to represent different types of usage/location of urban greenery (terminology according to Juhásová and Ivanová, 2001): street plantings – SP, neighbourhood plantings – NP, main roadside plantings – MRP, park plantings – PP, special-purpose greenery – SPG. Altogether 300 birch trees grown in these five different types of usage/location were evaluated, 60 trees for each greenery type. Trees mechanically injuried, especially wounded by human activities (cut and broken branches, injured trunks) were excluded from the evaluation. The age of evaluated trees was between 10 and 35 years.

Disease symptoms caused by common fungal pathogens, especially leaf diseases were observed, however in context of withering and subsequent decline of birch trees, they were unimportant. Incidence of wood destroying fungi [*Piptoporus betulinus* (Bull. et Fr.) Karst., *Fomes fomentarius* (L.ex Fr.) Kickx and *Armillaria* sp. div.] that cause more important injury in our conditions (wood rots and canker disease) was recorded individually. Damaged trees without symptoms caused by commonly known fungal pathogens of birch were classified as trees damaged by unknown factors.

Presence or absence of *Cytospora betulicola* as an important causal agent causing damage to birch trees in urban environment was recorded based on the typical disease symptoms, especially crown changes and characteristic bark necrosis on branches and stems of affected trees. Scale also includes symptoms caused by common wood destroying fungi to birches.

Damage degree of the evaluated trees in the particular greenery types of usage/location was determined according to a six-point scale modified for the purpose of birch health state evaluation:

H: tree healthy, without visual symptoms of damage

1st degree: foliage decline in natural colour, leaf withering, sporadic incidence of thin dry branches in tree crown ⇨*Cytospora*; light brown discoloration, the wood remaining quite firm, tree withering, yellowing leaves ⇨ wood decay fungi

2nd degree: $^{1}/_{3}$ of the crown volume with dry branches, yelow-orange to orange-brown discoloration on bark tissues, elongate sunken necrosis on the bark of trunk and branches (>5 cm in length) ⇨ *Cytospora*; decayed wood is yellowish-brown and cracks into cubes with thin white mycelial mats forming in the cracks, sporadical incidence of grey to brown or black, woody or leathery and usually hoof shaped fruiting bodies, crown becomes more withered, reduction in tree growth ⇨ wood decay fungi

3rd degree: $^{1}/_{2}$ of the crown volume with dry branches, necrosis on the bark of stem and branches (>10 cm in length), the inner bark turns dark brown to black and the sapwood underneath light brown ⇨ *Cytospora*; wood in advanced stages of decay is light in weight and easily crumbles to powder, frequent incidence of perennial fruiting bodies, resinous exudation and presence of white fanlike syrrocium under the bark ⇨ wood decay fungi

4^{th} degree: $^{2}/_{3}$ of the crown volume with dry branches, necrosis on the bark of trunk and branches (>15 cm in length), formation of fruiting bodies (pycnidia) as short grey-black cones within the cankers ⇨ *Cytospora*; leathery, off-white or light brown fruiting bodies with a short, stout stipe grown out of the bark, wood with decay is yellow-white, strong white syrrocium under the bark of trunks, decayed wood is yellow with numerous black lines ⇨ wood decay fungi

5^{th} degree: tree dying, crown dry with sporadically living branches, large necrosis on the bark of trunk and branches, strong pycnidial exudation of orange to red-coloured sticky masses of conidia in hairlike coils, dead bark lifts away from the trunk and falls off in large pieces ⇨ *Cytospora*; large annual fruiting bodies with darker brown and scaly upper surface, wood with advanced decay is soft and spongy, frequently containing brown to black zone lines, small radial cracks filled with yellow mycelium may develop, fruiting bodies in the immediate surroundings of affected trees, frequent incidence of black rhizomorfs under the bark of died trees and in the soil ⇨ wood decay fungi.

Statistical analysis

The one-way ANOVA was used to evaluate the influence of locality (greenery type of usage/location) on damage degree of selected birch trees. Then all localities were compared with respect to damage degree using t-test (independent groups) including all 10 locality combinations.

Three factors were monitored occurring on birch trees (*Cytospora* fungus, wood destroying fungi, unknown factors). For determination of their influence on birch damage degree values the multifactorial analysis of variance (ANOVA) was applied.

The statistical package STATISTICA-7 (StatSoft) was used for all analyses.

Results

Data on phytopathological evaluation on birch trees in particular types of greenery usage/location were supplemented with damage degree categorization (Table 1). No disease symptoms were observed on 208 trees altogether from the total number of evaluated birch trees (300). Nearly 1/3 of the evaluated trees showed certain damage degree by disease symptoms. By the type of greenery usage/location, the most affected trees occurred in the main-roadside plantings (22 trees) and street plantings (21 trees).

On 62 trees altogether, disease symptoms caused by *Cytospora* fungus were recorded. The incidence of wood decay fungi was observed on 27 birches.

The one-way ANOVA did not confirm generally a significant influence of the locality ($F = 2.31$, $p = 0.058$; Fig 1) on the damage degree to birch trees. Significant differences in the damage degree values were confirmed between some greenery types by using t-test (Table 2). Only the type SPG differed from the SP ($t = 2.70$, $p = 0.01$), NP ($t = 2.20$, $p = 0.03$) and MRP ($t = 2.60$, $p = 0.01$).

Cytospora fungus and wood destroying fungi significantly influenced birch health decrease (damage degree increase). Using the multifactorial ANOVA, a significant influence of two factors, *Cytospora* fungus ($F = 13.24$, $p = 0.0003$) and wood destroying fungi ($F = 4.20$; $p = 0.04$) on damage degree increase was confirmed (Table 3, Fig 2a, b).

The unknown factor alone did not produce an important damage ($F = 0.07$, $p = 0.79$). It displayed only in combination with wood destroying fungi ($F = 52.10$, $p = 0.00$), Fig 2c. All effects are presented in Table 3.

Table 1. Results of phytopathological evaluation of birch trees in particular types of greenery usage/location in Nitra by damage degree

Damage degree	Number of trees in particular greenery types of usage/location														
	Street plantings			Neighbourhood plantings			Main roadside plantings			Park plantings			Special- purpose greenery		
	CB	WD	UF	CB	WD	UF	CB	WD	UF	CB	WD	UF	CB	WD	UF
1	2	–	–	3	–	–	2	–	–	8	–	–	3	–	–
2	6	1	2	7	–	–	10	1	1	4	2	–	2	–	–
3	4	4	1	1	5	–	–	3	–	1	2	–	2	2	–
4	3	3	1	–	–	2	2	4	2	1	–	–	–	–	–
5	1	–	3	–	–	3	–	–	2	–	–	2	–	–	1
Number (in 1–5)	16	8	7	11	5	5	14	8	5	14	4	2	7	2	1
H	39	40	38	41	50										

CB – *Cytospora betulicola*; WD – wood destroying fungi; UF – unknown factors; H – healthy trees

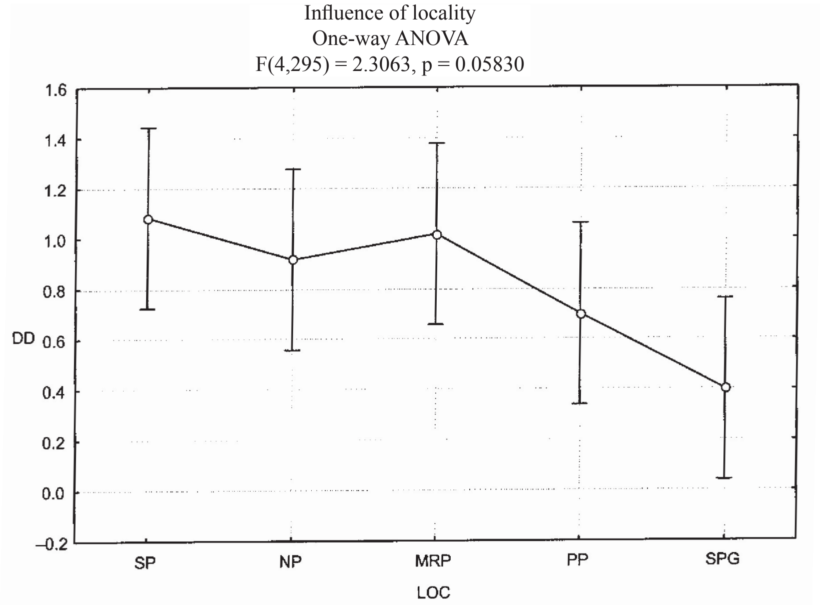

Fig 1. Influence of greenery usage/location type on damage degree to evaluated birch trees
x-axis: LOC – location (SP – street plantings; NP – neighbourhood plantings; MPR – main roadside plantings; PP – park plantings; SPG – special-purpose plantings)
y-axis: DD – damage degree (0–5)

Table 2. Comparison of particular types of greenery usage/location with respect to damage degree. Significant differences between relevant greenery types are in bold

Greenery type	Average damage degree	Standard deviation	SP	NP	MRP	PP	SPG
SP	1.08	1.67	×	t = 0.58 p = 0.57	t = 0.23 p = 0.82	t = 1.42 p = 0.16	**t = 2.70** **p = 0.01**
NP	0.92	1.50		×	t = –0.36 p = 0.72	t = 0.86 p = 0.39	**t = 2.20** **p = 0.03**
MRP	1.02	1.52			×	t = 1.24 p = 0.22	**t = 2.60** **p = 0.01**
PP	0.70	1.27				×	t = 1.42 p = 0.16
SPG	0.40	1.03					×

SP – street plantings; NP – neighbourhood plantings; MPR – main roadside plantings; PP – park plantings; SPG – special-purpose plantings

Table 3. Effects of all factors included in the analysis and their combinations. Significant factors are in bold

Significance tests for damage degree		
ANOVA	F	p
CB	13.2372	**0.000324**
WD	4.1957	**0.041421**
UF	0.0716	0.789140
CB*WD	8.1368	**0.004647**
CB*UF	0.2878	0.592024
WD*UF	52.0995	**0.000000**
CB*WD*UF	41.6398	**0.000000**

CB – *Cytospora betulicola*; WD – wood destroying fungi; UF – unknown factors

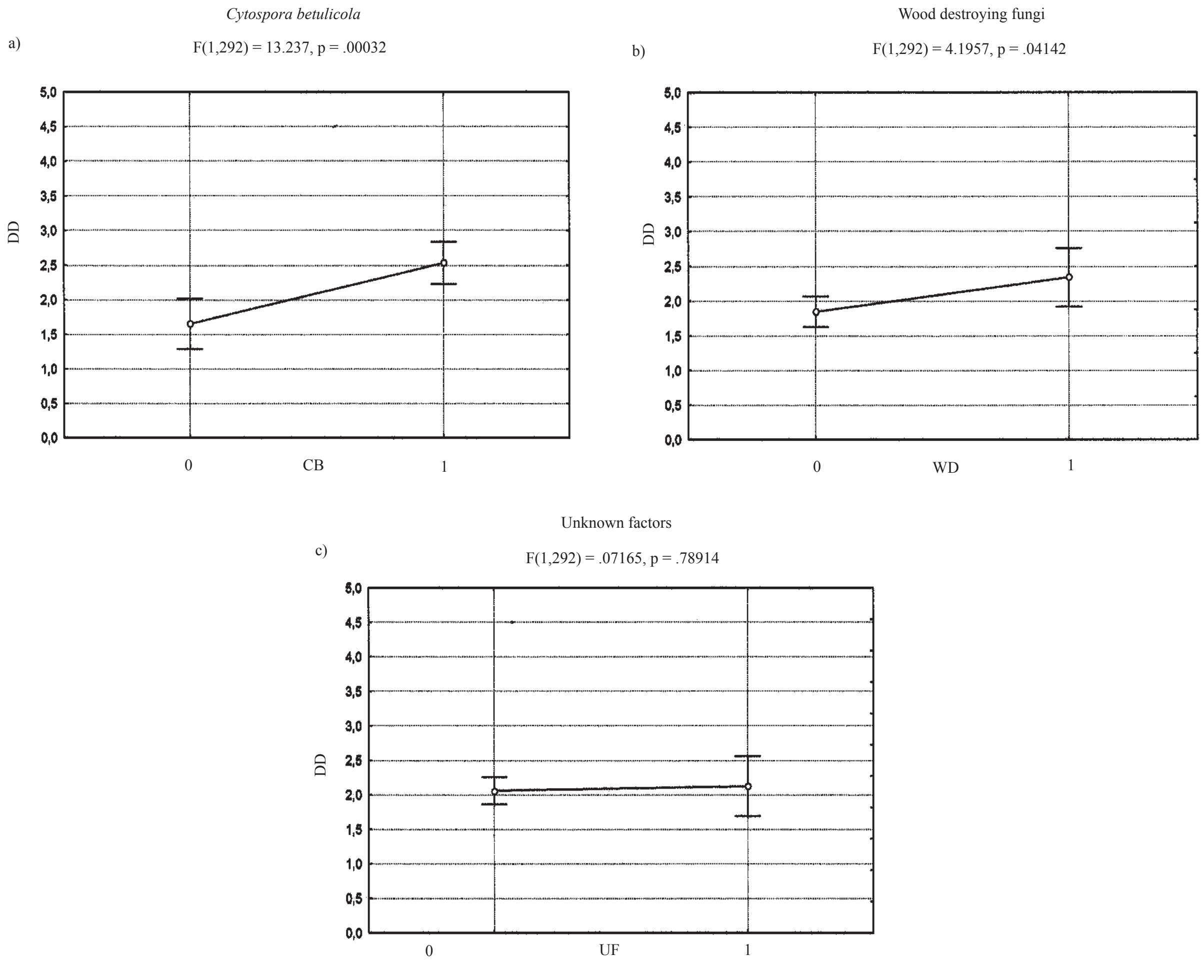

Fig 2a, b, c. Influence of three factors on damage degree to evaluated birch trees
x-axis: CB – *Cytospora betulicola*; WD – wood destroying fungi; UF – unknown factors
y-axis: DD – damage degree (0–5)

Discussion

Species of the *Betula* genus belong to trees often grown as markedly decorative woody plants in urban plantings. On a considerable number of birch species, *Cytospora* damage has been recorded. Disease caused by *Cytospora* is rarely a problem of economic importance in natural stands, but can cause serious damage to forest nurseries, young plantations, horticultural settings and to urban plantings in many countries (Allen et al., 1996). According to Cejp (1957), Spaulding (1961), Peace (1962), Ubrizsy and Vörös (1968), many species of *Cytospora* have been associated with tree damage and several species with dieback of trees. Many *Cytospora* species are only weak parasites and attack a wide range of trees and shrubs, including birch species with various injuries. Several studies (Juhásová and Gáper, 1986; Juhásová and Ivanová, 2003; Juhásová et al., 2005) on this problem in Slovakia have confirmed *Cytospora* fungi as an important cause of branch dieback and tree decline.

Juhásová (2004) states the fungus *Cytospora betulicola* Fautr. as a relatively common parasitic fungus of *Betula* sp. div. in urban plantings in Slovakia. The first disease symptoms appear as sudden chlorosis, withering and premature leaf fall shortly after foliation of the crown. Affected branches or whole trees die gradually. Trunk and branches are spread with abundant fungal stromata visible to the unaided eye after bark removal. Pycnidia with pycnospores – a source of the next infection are formed in stromata under the bark. Various damages caused mechanically by breaking of branches for decorative purposes, animals activity, strong hail and frost, unsuitable management measures and other activities are potential contributory factors of infection.

Quality and quantity of trees in the relevant greenery is influenced by bio-ecological factors. Healthy woody plants, without disturbances in physiological processes show high adaptative ability to the environment and have proportionally developed organs. On the contrary, unhealthy woody plants manifest quantitative and qualitative changes in their normal vital functions. The correct and timely classification and determination of these changes is the primary precondition for the effective practical protection (Heagle, 1970).

According to Kůdela et al. (1989), it is not possible to explain the spread of the disease and resistance of trees with a single factor. The connection between pathogen and host is a dynamic relation of two living systems which depends on physiological condition of both partners. It also can contribute to clarification why the damage degrees to birch trees evaluated in this study in various greenery types of usage/location in urban environment are different.

In the Czech Republic, Gregorová et al. (1995) confirmed the damage by *Cytospora* pathogens to many birch tree species. On birch trees, *Cytospora* has been shown to inhabit healthy bark, causing disease only in case of low-vigourous trees or branches or when the hosts are stressed by drought, injury, sunscald, fire or other pathological disorders. Presence of this pathogen generally indicates that the trees are under the stress (Allen et al., 1996).

According to Pataky (2000, 2003), each birch in decline is different because the stress varies with each tree and the particular site. There is no current epidemic disease on birch. In most cases, it appears that the early drought stress couples with a high soil pH value has probably stressed trees, predisposing them to infection by canker and dieback fungi. The appropriate treatment is not easy: it is necessary to remove dead branches to avoid problems with wood rot, water the trees in periods of drought stress, test the pH of soil. Basing on these observations, it is possible to determine whether an acidic fertilizer is needed, remove cankered areas from the wood where possible and last, study the particular needs of the planted birch species. Preventive measures include keeping tree healthy and avoiding wounding.

Physiological, chemical and biochemical processes which take place in plant organisms are needful to study together with the health condition of trees and influence of polluted urban environment on them (Heagle, 1970). Environmental conditions as well as ecological requirements of woody plants and their resistance to polluted environment also have influence on selection of tree species for urban plantings. Trees weakened physiologically and injured mechanically succumb to pests and fungal disease attacks easily. It is generally known that the woody plants grown in urban environment are in consequence of the polluted environment and other adverse factors weakened and more predisposed to infections. On the other hand, there is only a limited knowledge on influence of the changed environment on fungal organisms, especially on the parasitic fungi. Some fungal species become weaker and on the contrary, growth of others is activated (Příhoda, 1969). According to Heagle (1970), besides different responses to the polluted environment corresponding to the fungus species, there are also intraspecific differences connected with different host woody plants.

Cytospora is usually considered to be a problem for plants that are under stress with the fungal pathogen gaining entry through dead wood and wounds. Healthy, vigorous trees and shrubs seldom manifest *Cytospora* canker. For that reason, detection of basic causes of their injuries and the plan of effective protective measures should improve general health condition of the greenery in the changed environmental conditions (Juhásová, 1997).

This study aims at fungi of *Cytospora* genus seriously damaging trunks and branches of many broadleaved tree species, including birch. Many of them are planted in towns. Their withering in consequence of *Cytospora* is characterized by formation of typical cankers on trunk, branches, leafstalks and buds. Affected trees wither gradually and die back prematurely.

Damage degree to trees can be influenced by many factors. Generally, in urban environment woody plants are stressed, which results in withering and increased predisposition to fungal diseases. According to our observations, the worst health state and the highest damage degree was observed on birch trees growing in street plantings and along main roads, thus in conditions that affect the growth, development and tree vitality in an adverse way.

In this study pathogenic impact and harmfulness of the fungus *Cytospora betulicola* has been confirmed as influencing the health state of *Betula* species in urban environment. The damage degree increase depended more markedly on *Cytospora betulicola* presence than on presence of wood destroying fungi.

Since we observed disease caused by *Cytospora* mainly on trees of greenery type of usage/location in unsuitable conditions, we can confirm the presence of this disease as a factor generally indicating the birch trees being under the stress. For example, in Nitra, root systems of trees situated along pavements or directly in asphalt or stone pavings in street plantings are reduced in development. Spreading of roads with salts with heavy metals content also influence negatively health state of woody plants grown in the immediate vicinity of the roads (mainroad plantings). Tree plantings between building blocks are often damaged mechanically by breaking and cutting of branches and destructions of trunks (vandalism). It causes increased susceptibility of the damaged trees to many harmful agents.

Occurrence of disease symptoms caused by other common fungi, especially occurrence of leaf diseases was observed, too. In aspect of withering and subsequent decline of birch trees, however, these symptoms belong to less important ones.

This study aimed at fungi of *Cytospora* genus on *Betula* sp. div. has confirmed importance of the fungus *Cytospora betulicola* Fautr. as the agent seriously damaging birch trees growing in urban greenery in Slovakia. Further experimental work in the field and in laboratory conditions is needed for more specific determination of pathogenicity of *Cytospora betulicola* Fautr.

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Význam cytospórového poškodenia vo vzťahu k zdravotnému stavu briez v mestskom prostredí – demonštrovaný na príklade mesta Nitra

Súhrn

V priebehu vegetačného obdobia rokov 2005–2007 bol s primárnym dôrazom na výskyt huby *Cytospora betulicola* Fautr. zhodnotený zdravotný stav druhov rodu *Betula* na príklade hodnotenia výsadieb briez v meste Nitra. Stupeň poškodenia vybraných stromov v piatich typoch funkčnej zelene (uličné výsadby; výsadby obytných častí mesta; výsadby popri hlavných cestných komunikáciách; parkové výsadby; špeciálne účelová zeleň) sme určili vo vzťahu k výskytu troch faktorov: huby *Cytospora betulicola* Fautr.,drevokazných húb a neznámych faktorov podieľajúcich sa na zhoršení zdravotného stavu drevín. Jednofaktorová analýza variancie vo všeobecnosti nepotvrdila štatisticky významný vplyv typu funkčnej zelene na stupeň poškodenia hodnotených briez. Signifikantné rozdiely v hodnotách stupňa poškodenia boli potvrdené medzi niektorými typmi funkčnej zelene použitím t-testu. Z výsledkov t-testu vyplýva, že *Cytospora betulicola* a drevokazné huby sa na zhoršovaní zdravotného stavu briez podieľajú významnou mierou. Výsledky multifaktoriálnej analýzy variancie potvrdili signifikantný vplyv oboch faktorov, huby *Cytospora betulicola* a drevokazných húb na zvýšenie stupňa poškodenia hodnotených drevín.

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Variability of chlorophyll and nitrogen content in the leaves of two-year-old seedlings of European chestnut (*Castanea sativa* Mill.) of different origin

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Abstract

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Two-year-old seedlings of European chestnut derived from twelve 45year-old progenies grown at the permanent experimental plot in Horné Lefantovce were used in the study. The progenies originated from 12 old mother trees grown on four different localities of Slovakia (Jelenec, Horné Lefantovce, Tlstý Vrch and Duchonka). In 2006, at three different dates (June, August, September), indirect measurement of chlorophyll content by a portable device Chlorophyll Content Meter CL-01 (fi. Hansatech) was carried out in 180 seedlings (15 ones in each progeny). In August and September, also direct determination of chlorophyll *a* and *b* content was carried out in 81 seedlings from 9 progenies (after excluding progenies from Duchonka). In the leaves collected in August, nitrogen content was determined with a CNS 2000 Analyzer (LECO corp., USA). Variability of CL-01 values and chlorophyll content values was highly significantly influenced by date of measurement (the lowest CL-01 values in June), individual progenies and provenience (origin) of parental trees. The most distinct differences between the three studied proveniences were observed in chlorophyll *a*+*b* content in the August sampling. Correlation between N content and chlorophyll content was medium strong (r = 0.413 and 0.419).

Key words

chlorophyll *a* and *b*, CL-01 values, nitrogen, progenies, localities

Introduction

Characterisation of genotypes or populations of woody plant species by the chlorophyll content and related bioelements is not very common, but in the last decades many studies occur on indirect chlorophyll content determination in assimilatory organs of crops, grassland and woody plants. In these studies predominantly portable chlorophyll meter SPAD-502 (Minolta, Japan) has been used.

Data obtained by this device were utilized to predict nitrogen content in plants and subsequently to determine an optimal level of nitrogen nutrition in crops and grass (Wood et al., 1993; Gáborčík, 1999; Shapiro,1999). In winter wheat and barley, variability of SPAD values was significantly influenced by cultivars and was in strong correlation with nitrogen content (Užík and Žofajová, 1998; Užík et al., 1999; Užík and Žofajová, 2000a; Užík and Žofajová, 2000b). The authors recommended this method for the selection of genotypes with different N-uptake and N-use efficiency. By SPAD values also Mg content in dry matter of grassland were examined and differences between grass species and cultivars were observed (Míka, 1980). Fanizza et al.(1991) observed that SPAD values measured in apical, fully developed leaves of *Vitis vinifera* are good indicator for screening genotypes on drought tolerance. Hoel (2002) proved, by measurement with a Hydro N-Tester (HNT), a portable chlorophyll meter, differences in leaf chlorophyll content between cultivars of winter wheat.

Studies of chlorophyll content in leaves of woody plant species with the aim to detect genotype differences or origin are very sporadic. Bonneville and Fyles (2005) estimated the relative chlorophyll content and leaf nutrient concentration by the SPAD-502 chlorophyll meter in the leaves of trembling aspen. The best representation of overall leaf chlorophyll was found when six SPAD readings were taken at different locations on each leaf. There was a positive correlation between overall leaf N and estimated chlorophyll content, especially in the top part of the trees. Ichie et al. (2006) reported a significant positive correlation between the actual chlorophylle content and the SPAD-502 readings and less positive correlation between the actual N content and the SPAD-502 readings in leaves of 10 woody plant species. Based on the results of Bauerle et al. (2006), the SPAD meter could be used to provide a rapid estimate of leaf absorbance and transmittance in the 400–700 nm wavelength range in woody plant species.

Within eco-physiological research, our present investigations have been aimed at the measurement of selected physiological characteristics (parameters of chlorophyll *a* fluorescence, chlorophylls *a, b* content) and subsequent evaluation of physiological status of introduced woody species *Quercus rubra* L., *Juglans nigra* L., *Castanea sativa* Mill., growing under different stand conditions at permanent experimental plots (Kmeť and Šalgovičová, 2003, 2004).

The main objective of this work is to examine the possibility to exploit data of indirect measurement of chlorophylls *a* and *b* for detection of different origin of European chestnut progenies and also for early test of growth performance and production abilities of these progenies.

Material and methods

Material and sampling

The field part of the study was carried out in the forest nursery within area of village Lovce. This nursery called officially Nursery center Hladomer belongs under the national company Forests of the Slovak Republic, enterprise Semenoles Liptovský Hrádok. It is situated at an altitude of 310 m asl at the foothill of the Tribeč Mountain. Soil in the forest nursery is clayey and on the place with our experimental plot has pH 7.2, content of phosphorus 233 mg, potassium 231 mg and magnesium 295 mg per 1kg of dry soil.

Fruits for growing seedlings were collected from 45year-old progenies derived from 12 old mother trees grown on four different localities of Slovakia, 3 trees from each locality (Jelenec, Horné Lefantovce, Tlstý Vrch and Dolné Príbelce). From each progeny at the time of fruit fall in 2004, about 150 fruits were randomly collected and stored in plastic bags in refrigerator at temperature of about 5 °C. In the mid of April 2005, healthy, germinated or not germinated 90 fruits, were selected from each of 12 samples then divided to three batches of 30 pieces and planted in randomized blocks in three replications.

During the vegetation period 2006, in each of 12 F2 progenies 15 seedlings, 5 in each replication, showing different growth intensity, were selected for investigations. Indirect measurement of chlorophyll content was carried out in all 180 selected seedlings while direct measurement, because of its technical demands and time consuming character, was carried on the reduced number of 81 seedlings in the reduced number of progenies (9 progenies after omitting progenies from Duchonka).

Indirect measurement of chlorophyll content

Indirect measurement was carried out on three successive dates during the vegetation season (June, July, September), each time on 5 leaves selected in acropetal order on the current main shoot or on the most vigorous lateral shoot (in September). At the first sampling date, in June, measurement was done directly on the plants without tearing off leaves. At the second and third dates the leaves were torn off, transferred in the portable cool-box to the laboratory and subjected to the measurement on the same or next day.

Indirect measurement of chlorophyll content was carried out with a portable device Chlorophyll Content Meter CL-01 (fi. Hansatech). Measurements were made either on two spots of leaf – in its middle and on its top or on three leaf spots – on the base, in the middle and on the top, always on the left side of leaf (viewed to the leaf face). Only at one date, CL-01 values were measured on both the left and the right half of the leaf with the aim to assess differences in CL-01 values between the left and right leaf half.

Direct determination of chlorophyll content

Direct determination of chlorophyll content was carried out two times in a season (August, September) immediately after measurement of CL-01 values.

Leaf samples for quantitative analysis of chlorophylls were collected by disc method. Circular discs with diameter of 8.3 mm were cut off with a metal borer on two places – in the middle and on the top of leaf on both right and left half of the leaf. Thus ten discs from the middle and ten discs from the top of leaf obtained per seedling were analyzed separately. Leaf discs were homogenized and processed according to the routine method. Absorbance values of chlophylls *a* and *b* were determined by a spectrophotometer Spekol-211. Calculation of chlorophyll content was done according to Lichtenthaler (1987) applied for weight unit of leaf dry matter (mg g^{-1}).

Determination of nitrogen content

The same leaf samples that were used for indirect and direct chlorophyll content measurements respectively were also used for the analysis of nitrogen content. The leaves were dried up in a drier at 65 °C until their weight remained stabile. The dried leaves were processed in two ways: first they were cut to small pieces and from this sample a batch of 0.2 g was analyzed and then the pieces were grounded with a mixer to powder from which also 0.2 g was analyzed. Nitrogen content was determined on CNS 2000 (LECO corp., USA) Analyzer working on principle of Dumas method (at 1,000 °C). As this method also allows to determine sulfur and carbon simultaneously with nitrogen so these two elements were also determined in our samples.

Data evaluation

Data obtained from indirect measurement of chlorophyll content (values CL-01), direct measurement of chlorophylls *a, b*, determination of N, C and S and morphometric data of the studied seedlings were evaluated by multifactorial analysis of variance – hierarchic model GLM and correlation analysis using statistic program package STATGRAPHIC PLUS 5 for Windows.

Results

Variability of CL-01 values

CL-01 values, obtained using the chlorophyllmeter device, were highly significantly influenced by all assumed sources of variance: spacial replication of the trial, date of measurement (June, August, September), provenience of mother trees from which F1 generation was derived (Tlstý Vrch, Horné Lefantovce, Jelenec, Duchonka), progeny of F1 generation within provenience (3 progenies within provenience), leaf position on the annual shoot (5 leaves in acropetal order) (Table 1). Also when CL-01 data were analysed separately on particular sampling dates, significant effect of progenies, leaf position and reading position on the leaf was proved influencing their variation. However, no one of the assumed interactions was proved as significant (Table 2).

In average, the lowest CL-01 values were observed on the first sampling date in June, nearly two-times lower than in August and September dates, respectively (Table 3). Localities were ranked as follows, from the lowest to the highest CL-01 values: Jelenec, Horné Lefantovce, Tlstý Vrch, Duchonka. There were, however, differences between progenies within each origin, and they were very rare ranked into one homogenous group in case when evaluation was done for all dates total. In case of single dates, progenies from one origin occurred more often in one homogenous group (Table 3). For instance, at the first date all progenies of Duchonka and Horné Lefantovce origin and at the second date all progenies of Tlstý Vrch were in a single group. At the third date maximum two progenies of one origin occurred in a single group.

Ranking the progeny means of CL-01 values was similar in all the three sampling dates what also correlation coefficients (r = 0.61–0.67) between CL-01 values from particular samplings suggest (Table 4). Some progenies showed at each date either the highest (HL A) or the lowest CL-01 values (DP 3). However, correlation between CL-01 means for seedlings from particular dates was very low (r = 0.13–0.36). Individual variation of CL-01 values within particular progeny was rather high in each date and could be affected by different environmental factors.

Table 1. Results of the multiple analysis of variance of CL-01 values obtained from measurement in the leaves of two-year-old seedlings derived from 12 progenies of European chestnut

Source of variation	Df	MS
Spatial replication of trial	2	1,137.84**
Date of measurement	2	15,648.1**
Origin (locality)	3	232.32**
Progeny (within locality. date and replication)	72	139.5**
Date × locality	6	240.02**
Leaf	4	80.25**
Residual	6,656	6.23
Total	6,745	

** P < 0.01

Table 2. Results of three multiple analyses of variance of CL-01 values obtained from measurement in the leaves of two-year-old seedlings at three different dates (June, August, September)

Source of variation	Df	MS – June	MS – August	MS – September
Progeny	11	49.1018**	174.955**	175.064**
Leaf	4	136.222**	223.218**	52.2187**
Position on leaf	1	93.5165**	279.682**	253.027**
Progeny x leaf	44	3.7709	9.3846	6.1807
Progeny x position	11	1.2515	1.0263	1.9919
Leaf x position	4	0.6145	1.0438	0.7306
Residual	1,724	2.9847	7.4927	11.9251
Total	1,799			

Table 3. Results of the multiple comparison of LS means of CL-01 values measured in three different dates (June, August, September) in two-year-old seedlings derived from 12 progenies of European chestnut of different origin (TV – Tlstý Vrch; HL – Horné Lefantovce; D – Duchonka; J – Jelenec)

June								August							September						
Progeny	CL01 Mean	Homogenous groups						Progeny	CL01 Mean	Homogenous groups					Progeny	CL01 Mean	Homogenous groups				
J 11	4.04	×						D 3	8.52	×					D 3	7.96	×				
J 5	4.50		×					J 11	8.95	×	×				J 11	8.71	×				
D 3	4.63		×	×				D 13	9.00		×				TV 2	9.84		×			
D 13	4.67		×	×				J 5	9.12		×				J 2	9.89		×			
TV 8	4.92			×				HL 17	9.25		×				J 5	10.38		×	×		
D 5	4.95			×	×			J 2	9.42		×	×			TV 8	10.49		×	×	×	
J 2	5.33				×	×		HL 18	9.86			×			HL 17	10.53		×	×	×	
TV 2	5.34				×	×		D 5	10.30				×		D 13	10.86			×	×	×
HL 17	5.44					×		TV 8	10.44				×		HL 18	11.02			×	×	×
TV 9	5.47					×		TV 2	10.52				×	×	TV 9	11.12				×	×
HL 18	5.68					×		TV 9	10.68				×	×	D 5	11.36					×
HLA	6.08						×	HLA	10.90					×	HLA	11.59					×
Mean	5.09								9.75							10.32					

Table 4. Correlation coefficients between CL01 obtained in three different dates (June, August, September) based either on seedlings means (n = 180) or on progeny means (n = 12)

	June	August
August	0.3583**	
n = 180	0.6737*	
n = 12		
September		
n = 180	0.1277	0.2946**
n = 12	0.6139*	0.6734*

** P < 0.01

Variability of chlorophylls *a* and *b* content

Content of both chlorophylls in leaves of chestnut seedlings was significantly influenced by origin of progenies and by progenies themselves and seedlings within progeny. Collecting date influenced significantly only content of chlorophyll *b* and replication of trial influenced content of chlorophyll *a* (Table 5).

In August, content of both chlorophylls was the lowest in seedlings of Jelenec origin, and the highest in seedlings of Tlstý Vrch origin (Table 6). On the contrary, in September, seedlings of Jelenec origin exhibited on average the highest while seedlings of Tlstý Vrch origin the lowest content of both chlorophylls. On both dates, content of chlorophyll *a* was highly significantly influenced by trial replications – the highest chlorophyll *a* content was observed in the third replication and the lowest one in the first replication.

Variability of characteristics related to the chlorophyll content

Nitrogen concentration in the leaves of 81 seedlings was not significantly affected by any of the assumed sources of variation (Table 7). Carbon and sulphur concentration in the same seedlings was highly significant affected by the progeny origin but only in the variant of analysis based on the grounded leaf matter. Concentration of both elements was higher in the progenies of Tlstý Vrch origin (Table 8).

Weight of leaf dry matter was statistically significant influenced by replication of experiment and progeny origin. It was significantly higher in seedlings of Horné Lefantovce origin than in the remaining seedlings.

Height and diameter of seedlings were significantly influenced by replications. The highest seedlings were in the first replication and the lowest ones in the third. Seedling height varied also by progeny origin.

Table 5. Results of the analyses of variance of chlorophyll *a*, chlorophyll *b* and chlorophyll *a* + *b* data obtained in two sampling dates (August. September) in leaves of two-year-old seedlings of European chestnut derived from 9 progenies of three different origins

Source of variation	Df	MS Chlorophyll *a*	MS Chlorophyll *b*	MS Chlorophyll *a+b*
Origin	2	1.3245**	0.3567**	3.0419**
Progeny (within origin)	6	0.5452**	0.0591*	0.8568*
Seedling (within progeny)	34	0.3059*	0.0402*	0.5587*
Date of sampling	1	0.2255	0.5803**	1.5305*
Position on leaf	1	0.0861	0.0313	0.2214
Replication of trial	2	0.7557*	0.0524	1.2060*
Date × position	1	0.0082	0.0004	0.0052
Date × seedling	34	0.1936	0.0220	0.3339
Position × seedling	34	0.0455	0.0055	0.0805
Residual	208	0.1782	0.0237	0.3216
Total	323			

* $P < 0.05$, ** $P < 0.01$

Table 6. Mean values of chlorophyll *a* and chlorophyll *b* content (in mg g^{-1} of dry matter) in the leaves of two-year-old seed lings derived from 12 progenies of European chestnut

	Chlorophyll *a*		Chlorophyll *b*	
Progeny	August	September	August	September
HL 17	1.58	1.68	0.56	0.51
HL 18	1.97	1.58	0.72	0.49
HL A	1.70	1.75	0.66	0.50
Mean	**1.75**	**1.67**	**0.64**	**0.50**
J 2	1.66	1.67	0.43	0.52
J 5	1.48	1.80	0.52	0.56
J 11	1.27	1.83	0.47	0.58
Mean	**1.47**	**1.76**	**0.47**	**0.55**
TV 2	1.62	1.59	0.63	0.53
TV 8	2.40	1.56	0.88	0.51
TV 9	2.10	1.58	0.70	0.49
Mean	**2.04**	**1.57**	**0.73**	**0.51**
Mean	**1.75**	**1.67**	**0.61**	**0.52**

Table 7. Results of the analyses of variance (GLM model) of 14 characteristic values measured in 81 two-year-old seedlings of European chestnut derived from 9 progenies of different origin. All data except those for height and diameter of seedlings obtained from one sampling in August 2006

Variable	Mean squares (MS) for sources of variation				
	Replication of trial	Origin of progenies	Progeny within origin	Tree within progeny	Residual
Chlorophyll *a*	0.4088	2.0518**	0.6594**	0.1540	0.1955
Chlorophyll *b*	0.0239	0.4151**	0.0622*	0.180	0.2778
Chlorophyll *a* + *b*	0.630	4.2662**	1.0390*	0.2706	0.3597
CL01	29.919**	6.170	6.390	3.8760	4.0761
N[1]	0.0747	0.0314	0.0407	0.0445	0.0828
C[1]	0.5030	65.6188**	11.0921	4.1249	5.8407
S[1]	0.0839	0.8704**	0.0887	0.0623	0.0571
N_1[2]	0.080	0.0067	0.0734	0.0491	0.0950
C_1[2]	0.0203	1.0348	1.8502	1.3081	1.3382
S_1[2]	0.0000	0.0929	0.0612	0.0513	0.0643
Dry matter	1.4073*	1.4469*	0.3941	0.3168	0.3648
Leaf disk	0.2048	0.1604	0.0757	0.0880	0.1290
Stem height	7,036.67**	1,066.54*	198.67	269.58	209.05
Stem diameter	90.263**	9.871	10.234	9.600	9.458

Df for individual sources of variations are as follows: replication – 2, origin – 2, progeny within origin – 6, tree within progeny – 34, residual – 36. Df total (corrected) – 80
* $P < 0.05$, ** $P < 0.01$
[1]Data obtained from cut leaf samples, [2]Data obtained from grounded leaf samples

Relationship between characteristics related to the chlorophyll content

For correlation analysis between characteristics related to the chlorophyll, data from August sampling served as a basis (Table 9). At this date, medium strong positive correlation (r = 0.61 and 0.58) was calculated between values of CL-01 and chlorophylls *a* and *b* observed in particular seedlings. On the contrary, on the September date, very low correlation was between the mentioned two values (r = 0.22 and 0.17). Between nitrogen content analyzed from grounded leaves (N1) and content of directly measured chlorophylls *a* and *b* as well as CL-01 values, medium strong correlation was observed. Morphological characteristics of seedlings (leaf dry matter, stem height, stem diameter) did not correlate with chlorophyll, CL-01 and N data.

Discussion

Chlorophyll content in leaves may vary depending on both internal and external factors. The leaves grown in shade have higher chlorophyll content per weight unit compared with the leaves exposed to the sunshine (Masarovičová and Štefančík, 1990; Gratani and Foti, 1998). The higher content of the chlorophylls *a* and *b* was observed also in the leaves of black walnut, red oak and European chestnut, grown in the shade of canopy (Kmeť et al., 2001; Kmeť and Šalgovičová, 2003). It is also known seasonal fluctuation of chlorophylls *a* and *b*, which may display a various course (Duda and Masarovičová, 1976). The ratio between chlorophyll *a* and chlorophyll *b* is not fixed. Usually the content of chlorophyll *a* is three times higher than the content of chlorophyll *b* (ratio 3 : 1). Our results have proved this ratio and also seasonal fluctuation of chlorophyll content. In addition to that, also significant effect of provenience of parental trees on chlorophyll content in seedlings was observed.

In winter wheat, SPAD values (values obtained from indirect measurement of chlorophyll content, similar to CL-01 values) strongly correlated with N content in soil and with the wheat genotype and varied according to the reading position on the leaf (Užík and Žofajová 2000; Užík and Žofajová, 2003). The lowest SPAD value was read on the top of leaf and the highest one in the middle of the leaf what is in accord with our results.

Correlation between CL-01 values and content of chlorophyll *a* and *b* varied according to the date of measurement. While in the measurement at the beginning of August was this correlation medium strong, in the measurement in mid September it was low and not significant. Increasing or decreasing CL-01 values as well as chlorophyll content values from August

Table 8. Least square means and standard errors (in parenthesis) of physiological and morphological character values measured in 81 two-year-old seedlings of European chestnut derived from 9 progenies of different origin (locality). All data except height and diameter of seedlings obtained from the sampling in August 2006. Total means in single rows labeled with different letters are significantly different at $p < 0.05$ according to LSD test

Character (unit)	Locality/progeny											
	Tlstý Vrch				Horné Lefantovce				Jelenec			
	2	8	9	**Total**	A	17	18	**Total**	2	5	11	**Total**
Chlorophyll *a* [mg g^{-1}]	1.5913 (0.1617)	2.4147 (0.1617)	2.1948 (0.1617)	**2.0669 a (0.0933)**	1.6443 (0.1617)	1.5826 (0.1497)	1.9491 (0.1534)	**1.7253 b (0.0895)**	1.6592 (0.1630)	1.4661 (0.1616)	1.2609 (0.1617)	**1.4621 b (0.0936)**
Chlorophyll *b* [mg g^{-1}]	0.6230 (0.0609)	0.8785 (0.0609)	0.7317 (0.0609)	**0.7442 a (0.0352)**	0.6428 (0.0609)	0.5645 (0.0564)	0.7180 (0.0578)	**0.6417 a (0.0337)**	0.4330 (0.0614)	0.5176 (0.0609)	0.4719 (0.0609)	**0.4742 b (0.0353)**
Chlor. *a* + *b* [mg g^{-1}]	2.2217 (0.2233)	3.306 (0.2233)	2.9342 (0.2233)	**2.8206 a (0.1289)**	2.2667 (0.2233)	2.1471 (0.207)	2.6541 (0.2118)	**2.356 b (0.1237)**	2.0828 (0.2250)	1.9635 (0.2233)	1.746 (0.207)	**1.9308 c (0.1293)**
CL01 [no unit]	10.0527 (0.8514)	11.1835 (0.8514)	10.2687 (0.8514)	**10.5016 a (0.4915)**	11.4012 (0.8514)	8.7795 (0.7892)	9.8379 (0.8077)	**10.0062 a (0.4915)**	9.1293 (0.858)	9.6469 (0.8514)	9.2108 (0.8514)	**9.329 a (0.4928)**
N [mg g^{-1}]	1.9402 (0.1052)	1.9846 (0.1052)	1.9129 (0.1052)	**1.9459 a (0.0607)**	1.9375 (0.1052)	1.9140 (0.0974)	1.8096 (0.0998)	**1.8870 a (0.0582)**	1.9802 (0.1061)	1.8698 (0.1052)	1.7798 (0.1052)	**1.8766 a (0.0610)**
C [mg g^{-1}]	43.949 (0.8836)	44.185 (0.8836)	46.194 (0.8836)	**44.776 a (0.5102)**	43.485 (0.8836)	44.1 (0.8181)	41.13 (0.8384)	**42.905 b (0.4893)**	41.001 (0.8911)	41.801 (0.8836)	41.240 (0.8836)	**41.350 b (0.5120)**
S [mg g^{-1}]	1.0944 (0.0873)	0.8369 (0.0873)	0.8866 (0.0873)	**0.9393 a (0.0504)**	0.8070 (0.0874)	0.7593 (0.0809)	0.5869 (0.0829)	**0.7177 b (0.0484)**	0.6011 (0.0881)	0.5229 (0.0873)	0.5118 (0.0873)	**0.5453 c (0.0506)**
Leaf dry matter [g]	2.1847 (0.2208)	1.9398 (0.2208)	1.9975 (0.2208)	**2.0407 ac (0.1275)**	2.5971 (0.2208)	2.3698 (0.2446)	2.0927 (0.2095)	**2.3532 b (0.1223)**	1.6803 (0.2227)	2.1761 (0.2208)	1.7322 (0.2208)	**1.8629 ac (0.1280)**
Leaf disc [mg]	84.578 (4.211)	76.163 (4.211)	77.313 (4.211)	**79.351 a (2.431)**	74.27 (4.211)	74.029 (3.903)	73.01 (3.994)	**73.77 a (2.331)**	72.196 (4.243)	76.57 (4.21)	78.55 (4.21)	**75.772 a (2.437)**
Height of stem [cm]	47.7 (8.705)	46.567 (8.705)	45.667 (8.705)	**46.644 a (5.026)**	69.0 (8.705)	51.229 (8.070)	60.3 (8.259)	**60.176 b (4.820)**	43.833 (8.773)	51.967 (8.705)	46.05 (8.705)	**47.28 a (5.039)**
Stem diam. [mm]	14.148 (1.352)	11.699 (1.352)	12.523 (1.352)	**12.79 a (0.781)**	15.791 (1.352)	12.868 (1.253)	13.738 (1.283)	**14.132 a (0.749)**	13.198 (1.363)	14.306 (1.352)	14.606 (1.352)	**14.037 a (0.783)**

to September sampling was not regular in individual seedlings but certain regularity occurred in mean values for individual progenies especially for CL-01 values. Mean chlorophyll values varied mostly irregularly – for instance in seedlings of Tlstý Vrch and Horné Lefantovce origin decreased but in seedlings of Jelenec origin increased from August to September. Explanation of these results needs apparently a new experiment and especially new analysis of chlorophyll content on a new device. Namely the old device for determination of chlorophyll content might be the reason of low correlation between values of direct and indirect chlorophyll measurements observed in our work. Literature data point mostly at strong correlations between chlorophyll content and SPAD values (Castelli et al., 1996; Yamameto et al., 2002; Ichie et al., 2006)

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Table 9. Correlation matrix (Pearson correlation coefficents) for physiological and morphological characteristics based on data obtained from 81 two-year-old seedlings of European chestnut derived from 9 progenies of different origin

Characteristics	Chl_*a*	Chl_*b*	Chl_*a*+*b*	CL01	N	N1	C	S	Dry matter	Height
Chl_*b*	**0.906****									
Chl_*a* + *b*	**0.993****	**0.949****								
CL01	**0.607****	**0.584****	**0.612****							
N	0.206	0.118	0.186	**0.302****						
N1	**0.357****	**0.278***	**0.342****	**0.413****	**0.701****					
C	0.132	0.136	0.136	0.089	**0.336****	–0.049				
S	0.040	0.094	0.055	–0.086	0.200	0.092	0.252			
Dry matter	–0.112	–0.065	–0.102	0.000	0.273	0.220	0.201	0.106		
Height	–0.134	–0.036	–0.110	–0.084	–0.021	0.097	–0.108	–0.036	**0.554****	
Diameter	–0.252*	–0.239*	–0.253*	–0.013	0.037	0.087	–0.069	–0.067	**0.484****	**0.736****

* $P < 0.05$, ** $P < 0.01$

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Variabilita obsahu chlorofylu a obsahu dusíka v listoch dvojročných semenáčikov gaštana jedlého rôzneho pôvodu

Súhrn

Ako pokusný materiál boli v práci použité dvojročné semenáčiky gaštana jedlého vypestované v lesnej škôlke Hladomer pri obci Lovce z plodov zozbieraných v roku 2004 na trvalej experimentálnej ploche v Horných Lefantovciach z 12 rôznych potomstiev vo veku 45 rokov. Tieto potomstvá pochádzali z 12 starých stromov zo štyroch lokalít Slovenska, tri stromy z každej lokality (Jelenec, Horné Lefantovce, Tlstý Vrch a Dolné Príbelce). V roku 2006 v troch rôznych termínoch (jún, august, september) sa robilo nepriame meranie obsahu chlorofylu v listoch semenáčikov pomocou prenosného prístroja – chlorofylmetra Chlorophyll Content Meter CL-01 (fi. Hansatech). V auguste a septembri následne po meraní chlorofylmetrom sa robilo aj priame stanovenie chlorofylu deštrukčnou metódou pri 81 semenáčikoch z 9 potomstiev (nehodnotili sa potomstvá z lokality Duchonka). Pri listoch zobraných v auguste sa zisťoval aj obsah dusíka na CNS 2000 analyzátore. Variabilita hodnôt nepriameho stanovenia chlorofylu (CL-01 hodnoty) ako aj priameho stanovenia chlorofylu bola štatisticky významne ovplyvnená dátumom odberu vzoriek, pôvodom – lokalitou materských stromov ako aj jednotlivými potomstvami v rámci jedného pôvodu. Hodnoty CL-01 boli najnižšie v júnových a najvyššie v septembrových vzorkách a hodnoty priameho stanovenia chlorofylu boli vyššie v auguste ako v septembri, no štatisticky významne iba pri chlorofyle *b*. Pri augustových vzorkách boli pozorované aj štatisticky významné rozdiely v celkovom obsahu chlorofylov (*a*+*b*) medzi semenáčikmi rôzneho pôvodu. Najvyšší obsah bol pri semenáčikoch pôvodu Tlstý Vrch, nižší pri pôvode Horné Lefantovce a najnižší pri pôvode Jelenec. V obsahu dusíka však neboli zaznamenané rozdiely medzi jednotlivými pôvodmi. Korelácia medzi obsahom chlorofylu a obsahom dusíka pri 81 sledovaných semenáčikoch bola len stredne silná (r = 0,413 a 0,419).

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Cell wall regeneration of protoplasts isolated from Norway spruce tissue cultures in a liquid nutrient medium

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Abstract

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Protoplasts isolated from spruce tissue culture (*Picea abies* L.) Karst. were incubated in a medium supplemented with D-/^{14}C/ glucose, with the aim to provide releasing radioactive oligosaccharides and polysaccharides. The amount of both in the medium was increasing over the entire 90-hour incubation period. We have confirmed that the secerned oligosaccharides are not formed in processes of hydrolysis running at the cytoplasmic membrane. The first are cell wall components accumulated through synthesis and then released from the being-created cell wall. A fluorescence microscope and a light one were our tools for study of protoplasts´ regeneration. The fluorescence reagent primulin was fixed on the protoplasts´ surface. Since 24 hours after the incubation, polysaccharidic cell wall components were deposed on the surface. All the protoplasts were covered with polysaccharidic material in three days after the incubation.

Keywords

Picea abies, protoplasts, secondary cell wall, oligosaccharides, polysaccharides

Introduction

Protoplasts of plant cells are a topical experimental material for study of cell wall regeneration. Protoplasts were isolated from plants for the first time by Cocking in 1960 (Cocking, 1960). The author used enzymes. Since then, protoplasts have been getting of increasing importance in a variety of branches in experimental botany. Protoplasts provide the most up-to-date and focussed tool in experimental breeding, because they offer completely new approaches for a more insightful look into genetic variability of cultural plants, either through transformation of their inborn genes or through somatic hybridisation. Protoplasts provide a powerful tool for evaluating marker gene expression in plants. Protoplasts can be used to regenerate whole trees; consequently, implementation of protoplast techniques for conifers is of crucial importance to forest biotechnology.

In conifers, protoplasts have also been isolated from seedlings (embryos, cotyledons, shoots) preconditioned in vitro by culture on a medium-containing auxin and cytokine before the protoplast isolation (David et al., 1982; Lang and Kohlenbach, 1989; Gómez-Maldonado, 2001; Malinowski and Filipecki, 2002).

Although protoplasts have been isolated from haploid cells of conifers, including pollen of *Cupressus arizonica* (Duhoux, 1980) and female gamethophytes of *Picea abies* (Hakman et al., 1986), most of the efficient preparation methods use callus or suspension cultures as starting materials (Kákoniová and Labudová, 1987).

Material and methods

The tissue culture of Norway spruce was obtained from hypocotyls of germinated spruce seeds and cultivated on a basic MS medium, modified according to Brown-Lawrence (1968).

We started our experiments with tissue cultures obtained from the just discussed seedling hypocotyls. The mixture of enzymes (5% cellulase, Onozuka R-10“ and 2% macerozyme R-10 in 0.4 M manitol) was supplemented with approx. 6 g spruce tissue culture. The incubation was running in a water bath, at 30 °C, for 5 hours, under continual stirring. Then the mixture was filtered, washed with 0.4 M manitol and processed in a centrifuge at 1500/min The sediment was separated through another centrifuging at 1500/min and a centrifuging at a dextrane gradient (15%, 10% and 5% dextrane, 6 ml each) at 3500/min. In 15 minutes, we succeeded to separate the protoplasts from cells or cell clusters. The fraction of pure protoplasts was obtained after removing dextrane through three times repeated washing with 0.4 M manitol and subsequent 10 min centrifuging at 1000/min.

We used the method of paper descending chromatography on Whatman 1 in the system S_1 – ethyl-acetate, n-propanol, water (1 : 7 : 2) and in the system S_2 – ethyl-acetate, pyridine, water (8 : 2 : 1).

Chemical detection of saccharides was carried out in solution of 20 µl saturated $AgNO_3$ dissolved in 40 ml of acetone and in solution of 0.5% NaOH dissolved in 75% ethyl alcohol.

Radioactivity of the samples was measured with a liquid scintillation equipment "Packard 3300" with scintillation solution consisting of: 5 g PBD, 100 mg POPOP, 1 l toluene.

Cleared protoplasts suspended in 0.4 M manitol were sealed into a liquid agar medium. The suspension of cleared protoplasts (100 µl) was supplemented with 50 µl of fluorescence reagent – primulin for staining polysaccharides. Photographing of microscopic specimens was performed with a fluorescence microscope (ZEISS, Jena, projector 4 : 1, objective G249, filter B-224 g).

Results and discussion

Protoplasts isolated from spruce tissue cultures at exponential phase of their growth were maintained in an environment consisting of 0.4 M manitol with stabilised osmotic pressure. The dimensions of cells embedded into this environment were the same as the original ones. Such treated protoplasts were transferred onto the liquid agar medium. Four or five days later, stable, non-lysing protoplasts began to appear. This means that these protoplasts had already synthetised cell wall components in sufficient amounts.

The cell wall regeneration of protoplasts was studied in experiments in which the cultivation medium without saccharose was added with D-/^{14}C/ glucose. Over the first four days, we explored radioactive carbohydrate metabolites released into the liquid nutrient medium. The incubation mixture consisted of 1 ml nutrient medium, 4 µci /^{14}C/ glucose and 2.10^4 protoplasts – suggesting that the protoplasts released oligosaccharides and polysaccharides into the cultivation medium. The amount of the released compounds was increasing with incubation time. This means that immediately after the embedding of the isolated protoplasts in the cultivation medium, the protoplasts started with synthesis of their cell wall components. The amount of radioactive glucose added to the medium at the beginning decreased rapidly with cultivation time, on the other hand, the amounts of released oligosaccharides and polysaccharides were progressively increasing.

The viability of protoplasts was evaluated on the amount and rate of utilization of D-/^{14}C/ glucose supplemented to the medium. We have found that the protoplasts (2.10^4) utilize D-/^{14}C/ glucose for the first seven days (Table 1). Later, there occurred changes in percent presence of the individual oligosaccharides (Table 2).

The released oligosaccharides can be separated in approx. three groups: A, B, C based on the chromatographic mobility of the first. Re-chromatography of the fractions in the system S_2 (48 h) did not resulted in any further distinction; therefore, we subjected the fractions to hydrolysis with 1 N HCl. The subsequent chromatography of the hydrolysate in the system S_2 (48 h) resulted in indication of presence of radioactive glucose and galactose and non-radioactive manose, xylose and arabinose.

The cultivation medium was supplemented with released oligosaccharides and polysaccharides. In a liquid cultivation medium, these compounds are evidently flushed away from the building cell wall, and their activity is dependent on biochemical composition of the cell wall (Fry et al., 1993; Malinowski and Filipecki, 2002). We needed to confirm that the released oligosaccharides did not originate in processes of hydrolysis taking place at the cytoplasmic membrane – either as the result of absorption of enzymes used in the protoplasts treating or as the result of presence of hydrolysing enzymes at the membrane. For this purpose, we transferred protoplasts incubated in the medium supplemented with D-/^{14}C/ glucose (4 µCi/ml) into the identical medium, but without D-/^{14}C/ glucose. At specified time intervals (30 min, 16, 22, 48, 54 and 120 h) we took aliquot samples of the medium, and investigated, through chromatography (Whatman 1, system S_2), the presence of radioactive oligosaccharides and polysaccharides expected to release into the liquid medium by effect of enzymes present in the cytoplasmic membrane. However, not even after a 90-hour incubation of protoplasts embedded into the nutrient medium, there were no radioactive oligosaccharides and polysaccharides released into the medium. In such a way, we have confirmed that the last are not originated in the cell wall hydrolysis at the cytoplasmic membrane, but that they are transported from the cytoplasm to the cytoplasmic membrane and to the cell wall being formed and through this cell wall, finally, into the liquid medium.

Table 1. Viability of protoplasts (2.[10-]4) according to quantity and rate of use of D-/^{14}C/ glucose on medium MS with saccharose

Fractions / incubation time (hours)	½	24	48	168	192	240
1	0.54	3.59	5.69	7.46	7.11	8.61
2	0.42	1.42	2.05	3.56	2.33	2.40
3	1.31	2.23	3.68	8.67	6.56	7.55
4	0.56	2.33	4.15	7.09	4.59	2.37
5	97.16	90.41	84.40	73.28	79.40	79.05

Table 2. Radioactivity of D-/^{14}C/ glucose (imp/min.) used in separate fractions on MS medium without saccharose expressed in per cents

Incubation time (hours) / fraction	½	24	48	168	192	240
	Amount (%)					
1	5.04	35.80	35.81	42.09	38.30	40.47
2	0.72	7.52	7.82	4.75	8.41	6.40
3	0.88	11.29	17.02	23.93	22.49	24.18
4	1.48	19.28	16.87	12.32	15.31	13.70
5	91.86	26.10	22.46	16.89	15.47	16.23

It has been well recognised that some growth substances, eg IAA and 2.4-D affect the building of polysaccharides in cell walls. For this reason, we first examined the stability of protoplasts in the liquid nutrient medium added with growth substances IAA and 2.4-D (0.1; 1; 5; 20 and 50 mg l^{-1}) in varying concentrations. The protoplasts were not lysed, not even after the 18-hour incubation in the medium supplemented with the growth substances in the just mentioned concentrations. After increasing the concentration values to 10^{-2} M (1,750 mg l^{-1}) and 10^{-3} M (175 mg l^{-1}) IAA, the protoplasts turned brown and started getting lysed.

The influence of growth substances on secretion of radioactive metabolites was studied on protoplasts incubated with 1 and 5 mg l^{-1} IAA, 1 and 5 mg l^{-1} 2.4–D and 1 mg l^{-1} kinetin (20,000 protoplasts per 1 ml of medium containing radioactive D-/^{14}C/ glucose and growth substance in appropriate concentration). At the given time intervals (30 min, 16, 22, 48, 54 and 120 h) we took aliquot samples of the medium. The last were processed through chromatography and detected for saccharides presence with an alkaline $AgNO_3$. The measurement of the material radioactivity revealed that, already 30 minutes after the incubation, the medium contained radioactive oligosaccharides the amount of which was increasing with the incubation time. No important differences, however, were identified in secretion between the studied hydro-carbonic metabolites depending on different concentrations of the used growth substances (Table 3). This effect of growth substances IAA and 2.4-D was suggested by several authors (Steveninck, 1965; Power and Cocking, 1970; Ray, 1973; Tanimoto and Igari, 1976) to explain by changes in protoplasts membrane permeability.

According to Capek et al. (2000), which works ourselves with research of polysaccharid galactoglucomannan from spruce, this polymer is not only a structural constituent of the secondary cell-wall, but lower fragments of this polymer (oligosaccharides) showed biological activity in elongation growth induced by auxin, in some morphogenic processes and in regenerating protoplasts.

Cell wall regeneration of protoplasts proving the viability of the isolated protoplasts was studied through fluorescence phenomenon – the fluorescence stain primulin was added to the medium containing protoplasts. The fresh isolated protoplasts only contained tiny residua of the cell walls (Fig 1a, b). After 24 hours of incubation, the protoplasts surface began to cover with cell wall components on which the stain is fixed (Fig 2a, b). After three days of incubation, we could observe deposition of polysaccharidic material on almost all the protoplasts (Fig 3a, b). Our results are in good accordance with the results obtained by Gómez-Maldonado et al. (2001), who prepared protoplasts by isolation from cotyledons of seedlings of *Pinus pinaster* by staining with fluorescein diacetate.

Table 3. Influence of growth substances on secretion of radioactive metabolites

Fraction / hours		0	15	22	48	54	120
1	K	0.21	30.63	46.37	52.72	51.27	42.55
	IAA	0.22	26.24	46.73	56.79	54.36	45.27
	IAA	0.25	34.27	45.18	45.30	54.26	53.90
	2.4-D	0.18	36.31	46.31	50.90	48.10	42.78
	2.4-D	0.23	17.37	35.78	54.77	57.21	60.30
2	K	0.63	10.77	16.84	25.02	27.70	31.08
	IAA	0.58	14.31	21.75	31.64	28.01	34.06
	IAA	0.61	13.70	21.20	30.46	31.89	32.24
	2.4-D	0.63	16.70	25.53	30.39	32.29	36.83
	2.4-D	0.57	6.79	12.96	24.08	25.28	20.66
3	K	–	6.59	9.30	11.55	10.86	10.29
	IAA	–	7.57	10.02	10.43	9.03	9.53
	IAA	–	7.01	9.40	13.74	15.11	6.92
	2.4-D	–	7.02	9.55	8.89	5.85	9.99
	2.4-D	–	4.59	7.71	9.92	8.28	5.19
4	K	99.15	52.02	27.39	10.75	10.16	10.06
	IAA	99.18	44.34	21.47	11.24	8.58	10.23
	IAA	99.13	45.01	24.23	10.47	8.72	6.86
	2.4-D	99.18	39.96	18.50	10.09	9.74	10.37
	2.4-D	99.18	71.23	43.52	11.22	9.21	5.75

IAA (3-indoleacetic acid) 1 and 5 mg l^{-1}
2.4-D (2,4-dichlorfenoxy acetic acid) 1 and 5 mg l^{-1}
K (kinetin) 1 mg l^{-1}

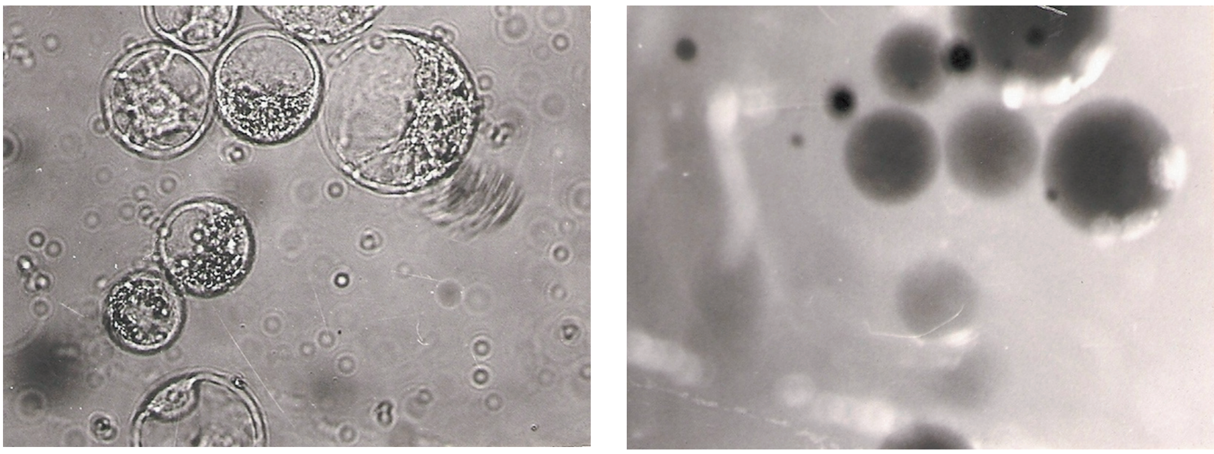

Fig 1a, b. Fresh isolated protoplasts only contained tiny residua of the cell walls
1a (light microscopy), 1b (fluorescence microscopy)

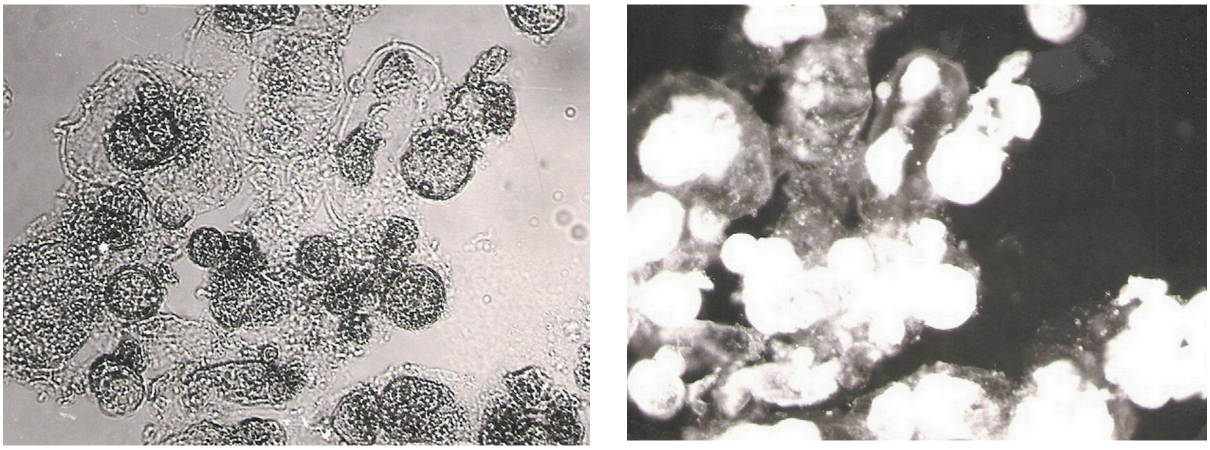

Fig 2a, b. After 24 hours of incubation, the protoplasts surface began to cover with cell wall components on which the stain is fixed, 2a (light microscopy), 2b (fluorescence microscopy)

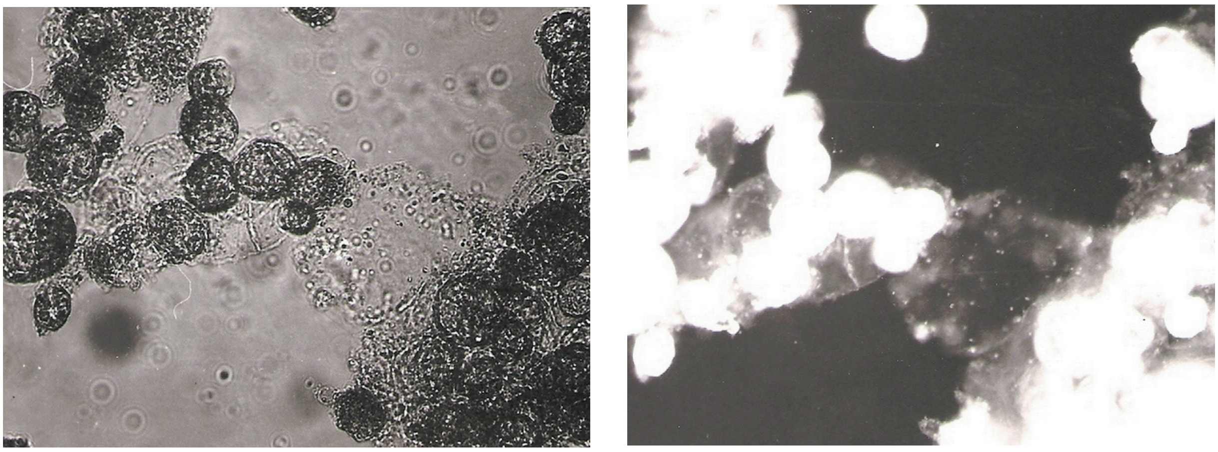

Fig 3a, b. Deposition of polysaccharidic material on almost all the protoplasts after three days of incubation 3a (light microscopy), 3b (fluorescence microscopy)

Conclusions

The method of protoplasts isolation from tissue culture of Norway spruce easily allows replications. Studying stability of protoplasts in medium with admixture of growth substances IAA and 2.4-D (0.1; 1; 5; 20; 50 mg l^{-1}) in varying concentrations, we have found that the protoplasts were not lysed, even after 128 hours of incubation. The concerned concentrations of growth substances had not significant influence on secretion of oligosaccharides and polysaccharides that are considered to be identifying the cell wall regeneration.

The incubation of protoplasts in the medium with admixture of D-/^{14}C/ glucose induced releasing radioactive oligosaccharides and polysaccharides into the medium. The amount of the released material increased over the whole 90-hour incubation period. It has been confirmed that the released saccharides were not a product of hydrolysing processes occurring at the cytoplasmic membrane, but that the first were synthesized cell wall components flushed away from the created cell wall.

The study of protoplasts viability confirmed that the protoplasts used D-/^{14}C/ glucose over the first seven days. In the following days, there occurred changes in percentages of the individual oligosaccharides caused by presence of hydrolytic enzymes in the cultivation medium.

The study of protoplasts regeneration pursued through fluorescence microscopy coupled with light microscopy revealed that there were no cell wall residues on surface of freshly isolated protoplasts. However, already after 24 hours of incubation, the protoplasts surface began to cover with polysaccharidic components of cell walls, fixing fluorescence stain primulin. After three days of incubation, we could observe polysaccharidic material deposition on practically all protoplasts.

Abbreviations

IAA	3-indoleacetic acid
2.4-D	2.4-dichlorfenoxy acetic acid
kinetin	6 furfurylaminopurine
primulin	mono and bi-dehydro-p-toluidine sulphonate
MS	Murashige and Skoog (1962)
BL	Brown and Lawrence (1968)

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Regenerácia bunkových stien protoplastov z pletivových kultúr smreka obyčajného (*Picea abies* L.) Karst. v tekutom živnom médiu

Súhrn

Regeneráciu protoplastov pripravených z pletivovej kultúry smreka obyčajného sme sledovali fluorescenčnou mikroskopiou v kombinácii so svetelnou mikroskopiou. Na čerstvo izolovaných protoplastoch nie sú zvyšky bunkových stien. Po 24 hodinovej inkubácii sa na povrch protoplastov ukladali polysacharidické komponenty bunkovej steny, na ktoré sa viaže fluorescenčné farbivo primulín. Po trojdňovej inkubácii sme prakticky na všetkých protoplastoch pozorovali ukladanie polysacharidického materiálu.

Pri práci s izolovanými protoplastami je dôležitá ich stabilita a životnosť. Stabilitu protoplastov sme sledovali v médiu s prídavkom rôznych koncentrácií rastových látok IAA a 2,4-D (0,1; 1; 5; 20; 50 mg l^{-1}). Protoplasty ani po 18-hodinovej inkubácii v tomto prostredí nelyzovali. Použité koncentrácie rastových látok nemali výrazný vplyv na sekréciu oligosacharidov a polysacharidov, ktoré sa považujú za znak tvorby bunkovej steny.

Zistili sme, že protoplasty inkubované v médiu s prídavkom D-/^{14}C/ glukózy secernujú do média rádioaktívne oligosacharidy a polysacharidy, ktorých množstvo sa počas 90-hodinovej inkubácie zvyšovalo. Potvrdili sme, že secernované oligosacharidy nie sú produktom hydrolyzačných dejov prebiehajúcich na cytoplazmatickej membráne, ale že sú to nasyntetizované komponenty bunkovej steny, ktoré sú odplavované od tvoriacej sa bunkovej steny.

Pri sledovaní životnosti protoplastov sme zistili, že protoplasty utilizujú D-/^{14}C/ glukózu počas prvých sedem dní. V nasledujúcich dňoch dochádza k percentuálnym zmenám v zastúpení jednotlivých oligosacharidov spôsobených hydrolytickými enzýmami, ktoré sú prítomné v kultivačnom médiu.

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Influence of substrate type and cultivation technology on quantitative characteristic of spruce (*Picea abies* (L.) Karst.) seedlings´ root systems: comparison between quantitative traits

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Abstract

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This work deals with evaluation of influence of four different management methods and substrate types on basic quantitative parameters of root systems in one-year old spruce (*Picea abies* (L.) Karst.) seedlings. There were tested differences between three alternatives consisting of bare-rooted plants and one variant of ball plants grown under applying the technique Lännen Plantek. The bare-rooted seedlings were cultivated in pure peat substrate (control) and in peat substrates supplemented with alginite and Baktomix. The tested traits were the following: root system weight, length, surface, volume, mean diameter and number of endings. For testing differences between the mean values of these characteristics, we used variance analysis. There has been found that in all the evaluated traits, the highest values were obtained with using the method Lännen Plantek. These values were several times higher that the next lower value. The variability of the measured values was about 30%. The lowest mean values were obtained in case of the peat substrate enriched with alginite. There is supposed that alginite caused water-logging of substrate and significantly retarded growth under the wetting regime favourable for all the other variants.

Key words

Norway spruce, root system, bare-rooted seedlings, ball seedlings, alginite, Baktomix

Introduction

Spruce is the woody plant most seriously affected by injurious agents, predominantly abiotic (wind). In recent years (2001–2005), the share of incidental felling in this woody plant was higher than 70% of the total amount (source: National Forest Centre Zvolen). The regeneration of deforested plots with the same woody plant is only possible with a considerable share of artificial regeneration.

Sarvaš et al. (2006) report that the Slovak forestry use bare-rooted seedlings in 97% of the total artificial regeneration. The using of this material takes for granted vigorous bare-rooted plants (Standard STN 48 2211). The growing up of such plants usually requires from two to four years, consequently, the producers are not able to respond the market's demands in an appropriately flexible way. This type of planting material is to a considerable extent dependent on the weather course, especially in case of spring lifting and following planting if the basic methodical rules are not complied with by storage. The cause is reduced vitality of such temporary stored material. If the harm caused by improper storing is coupled with unfavourable weather course after the planting, the result is a stronger transplanting-related shock followed by high losses at forestation. The expenses on repeated forestation in 2001 reached more than 160 mil. Sk, in 2003 the sum was higher than 130 mil. Sk (Anonymus, 2003, 2004).

Injurious effects of factors causing lowering the rooting rate in the planted material can be eliminated by applying hydro-absorbents (syn. soil conditioners, hydrosols) to plants grown in forest nurseries and in forestation process (Sarvašová, 2004; Sarvaš and Tučeková, 2004). The principle of their functioning is in their capacity to take up water, cations and anions and to maintain them in their "exchange" form, important for the uptake by plants. These substances promote the soil sorption complex to the extent enabling sufficient supply of water and nutrients to the woody plants. One of these substances is alginite – a tertiary sedimentary rock of organic origin (Vass et al., 2002).

Another possibility how to raise the total rooting rate in artificial regeneration is using ball plants. This type of planting material offers, in comparison with the bare-rooted one, a number of profits – in terms of biology, technology and commerce (Šmelková, 2001, 2004; Tučeková and Ábelová, 2002; Tučeková, 2003, 2004a), on the other hand, the shortcomings are discussed in Tučeková (2004a), Lokvenc (2001).

Baktomix™ is a macrobiological agent assigned for improving soil fertility. It consists of a mixture of active cultures of soil bacteria *Azotobacter chroococcum, Cellulomonas uda* and *Bacillus megaterium*. The use of this mixture can supply to certain extent or even fully the artificial fertilisers, through increasing the activity of nitrification bacteria resulting in improved decomposition of cellulose and increased amount of bound atmospheric nitrogen (source: http://www.agref.sk/baktomix.html).

Both the method and technology in plant material growing have impact on development of quantitative and qualitative parameters of both aboveground and underground parts of seedlings and plants. The values of these parameters have direct influence on the viability of the planting material, and, consequently, on rate of successful artificial regeneration. The growing speed in plants is primarily dependent on the uptake of water and dissolved nutrients, which in its turn depends on the root system's size. The correlation between the two factors is positive.

Material and methods

Experimental seeding trials were carried out on two plots: the first situated in the Arboretum Borová Hora, the second in the Forest Nursery Centre (FNS) Jochy, Semenoles Liptovský Hrádok. Both plots were established on May 2, 2006, following the technology *Lännen Plantek*. There was used the spruce seed provided by the School Forest Enterprise (SFE) Technical University in Zvolen: 093/01/03 EVK 01563ZV577 15/2003. The germination per cent was 99%, purity was 95%.

In the Arboretum Borová Hora, three experimental mini-plots, each 1m^2 in size, were sawn each with a 35 g batch of Norway spruce seed. Each plot was divided into three equal blocks. The seeding substrate was pure peat substrate from Suchá Hora (Orava region, N Slovakia). The first plot was supplemented with hydro-absorbent alginite in amount of 3 kg m^{-2} , the second with Baktomix 4 l m^{-2}, the third was left as control. The seeds were covered with a thin peat layer. The germination was observed on May 21, 2006. Over the whole vegetation period, the plots were treated in accordance with common agricultural engineering. Beginning with the first October week 2006, 35 seedlings from each block were lifted carefully in such a way as to avoid impairment of their root systems.

The seed of the same origin was also sawn in boxes with peat substrate at the FNC Jochy, Semenoles Liptovský Hrádok. The Norway spruce seed in number of 162 was planted into the trays with 81 cells with parameters listed in Table 1. The seedlings were cultivated in shelters, where there were wetted with fertilisersenriched water. In August and September, they were transported to open area with the aim to promote appropriate maturing of shoots and winter-resistance of the woody plant. On October 19, 2006, there was taken a sample consisting of 35 Norway spruce seedlings from the experimental seeding into Lännen Plantek trays.

The values of quantitative morphological characteristics of root systems of the examined one-year-old seedlings were determined using the direct destructive method. The root systems of the sampled plants were first of all thoroughly rinsed with water to remove the substrate. At the same time, it was necessary to take care and prevent tearing-off and loss of parts. If such prepared material was not possible to further process and analyse on the same day, it was stored in a fridge immersed in water for at most three days – to avoid its degradation (drying-out, growth of moulds, respiration, etc.). The washed seedlings were measured in diameter at their root collars with an accuracy of 0.05 mm, and separated into the aboveground and underground parts. The root length, volume and surface area as well as the number of root tips was determined using the software WinRhizo 2004a™ (Fig 1). The computer programme itself represents standard methods for determining these parameters. The output consists of the data about

Table 1. Parameters of Plantek-F seedling trays used in test sowing

Name	Number of cells per tray	Tray dimensions [mm]	Internal cell dimensions [mm]	Cell volume [cm^3]	Plant density [No m^{-2}]
PL 81F	9 × 9	385 × 385 × 73	41 × 41 × 73	85	549

the total length, average thickness, total surface area, volume and number of endings of the system or the section analysed. The output is provided in form of a text file easily importable into each table processor (eg Excel).

Fig 1. Example of a root system prepared for analysis with the WinRhizo software package (control, 1. block, 6. individual exemplar – weight 0.0623 g, root system's length 228.05 cm, surface area 27.67 cm^2, mean diameter 0.39 mm, volume 0.267 cm^3 and number of root tips 740)

The scanned root system was then dried up at a temperature of 60 °C for 72 hours with the aim to prevent loss, except free water, of other volatile substances, eg aromatic oils and turpentine which would discard the measurement reliability. Finally, the weight was determined with an accuracy of 0.001 g.

The statistical processing of the data was carried out with using the one-way variance analysis (ANOVA), for experiment designed in random blocks with different numbers of blocks in different variants. In terms of calculation of sum of squares, the method is the same as the one-way ANOVA with arranging without blocks. The block is embedded into calculation as a dummy second factor. The influence of this factor is not tested any more, its embedding, however, entails a considerable reduction in the residual variance. The value F is calculated as the ratio of the mean square (MS) of deviations associated with influence of the examined factor and MS associated with the blocks. The ANOVA analysis is followed by the Duncan's test in case when comparison between the variants is necessary or by the Dunnett's test if the modified variants are compared with the control. This method was used for verification of statistical significance of the total values (unpublished data).

This work presents first partial results of the experiment aimed at influence of various substrates and management methods used in spruce seedlings growing from seed.

Results

The size of root systems was compared based on comparisons between the mean values of the most important biometrical variables. The list of these values as well as fundamental data about the overall variability are summarised in Tables 2–7.

Examining the tables we can see that the differences between the mean values obtained in case of the Lännen – Plantek system and that obtained in case of bare-rooted plants grown in different modified substrates were manifold. The differences between the bare-rotted plants grown in different substrates were much smaller.

The variability of the measured values of the individual variables is rather low. As we can see in Tables 2–7, the values of variation coefficients reach about 30%, and the differences between the measured characteristics within one variant are much bigger than the differences between the variants in frame of one characteristic. The most variable characteristic was always the number of root tips; the lowest variability was observed in the mean root diameter. The exception was the variant Lännen, which might potentially be caused by the lower sample size. For each examined characteristic, the statistical significance of differences between the variants was tested with one-way variance analysis with randomised blocks. The results are listed in Table 8.

The results of variance analysis, namely the very high F-values, point out a high statistic significance of differences in means between the individual variants. The high value of the sum of squares the for variant (factor), and, consequently, the mentioned high F-value reflect the highly significant difference between the mean values in the variant Lännen and the mean values obtained in case of other – bare-rooted variants.

The comparison between the mean values of the studied biometric variables in individual variants and evaluation of statistical significance of the differences was carried out using the Duncan's test the output of which ranks the parameters into the individual homogeneous groups (Tables 2–7).

According to the results of the Duncan´s test carried out for the total length of roots, there have not been detected significant differences between the substrate supplemented with alginite and the control. Other homogeneous group comprised the control and Baktomix-enriched substrate. At the same time, also the difference in length between the substrate supplemented with alginite and the substrate supplemented with Baktomix was found statistically significant. The ball plants obtained using the Lännen Plantek methods were remarkably different from all the other variants (Table 2).

The classification of the variants into the homogeneous groups for the trait "root system surface area" is unambiguous. The first distinct group represents the variant with alginite in which there were found the smallest values of root system surface. The difference between the variant with Baktomix and the control was found to be random only (Table 3). The variant Lännen Plantek with ball plants is distinctly different from all the others. There are no overlapping homogeneous groups.

The evaluation of differences in average volume resulted in identification of the same relation as in case of root surface – the final ordering of the variants in case of this variable is increasing too, and the variants are clustered in three homogeneous groups with random within-group differences. The root volume of plants grown in alginite-enriched substrate was the smallest of all the variants. Baktomix caused almost no changes to the root volume compared with the control. Because the results of the Duncan´s test classified the last two variants (Baktomix and control) into one homogeneous group, we can declare the considered difference as random only.

Positive effect on root system formation in terms of volume has only the growing technology Lännen Plantek, for which there was found a mean value more than three times higher than the closest lower mean value. This variant also reached the highest value of volume density: 0.335 g cm^{-3} (Table 4).

The mean diameter of roots of the whole root system was the quantitative characteristic with the lowest variability (see Table 5). At the same time, this trait shows the smallest relative differences between the variants, except the pot-planting variant Lännen. The variance analysis revealed that, with regard to mean root thickness, the treated variants can be classified into two homogenous groups. The first consists of bare-rooted plants irrespective of substrate; the other group comprises ball plants only. Nevertheless, affiliation of the variant with Baktomix to the same group with control and alginite is close to the limit of statistical significance ($p = 0.056$). On the other hand, the hypothesis about difference in means between the control and the variant with alginite can be rejected with much more reliability.

Further we evaluated constant weight of the root systems. This characteristic, unlike those above discussed, can be measured quite easily and can provide an authentic pattern for biomass creation in different conditions. In case of weight of the whole root systems, the individual variants are grouped in the same way as in case of the overall length. The substrate with alginite and the control create one homogeneous group. The second group consists of the control and substrate with Baktomix. The third group again consists only of the ball plants grown using the method Länen Plantek (Table 6).

The number of root tips is a variable reflecting on one hand the root system's growth potential, on the other also its suction capacity. For this reason, in spite of the fact that this variable is quantitative, it rather describes the root system's quality. At the same time, it is the characteristic with the highest variability. In Table 7 we can see that the ball seedlings have almost four times more root tips than the other variants. The significance of differences between the endings number was evaluated by means of variance analysis. From the results listed in Table 8 we can conclude about the high significant differences between the variants. According to the results of the Duncan´s test (Table 7), the bare-rooted seedlings form one homogeneous group. From this group are different, with a high probability, ball seedlings obtained by means of the Länen Plantek method.

Tables 2–7 also contain relative shares of the important biometric variables. From their values it follows that the most distinct characteristic is the root mass, representing in the variant Lännen more than 580% of the root mass in the control. As for the other characteristics, in the Lännen variant they are two or even four times higher compared to the other variants.

Table 2. Comparison of basic statistical characteristics between individual variants, root length (cm)

Variant	Statistical characteristic						
	Mean	s_x	s_x [%]	Min	Max	%	Duncan*
Control	219.20	67.71	30.89	71.50	461.50	100.00	AB
Lännen	805.50	265.98	33.02	367.60	1,454.70	367.50	C
Alginite	192.70	50.32	26.12	97.90	390.90	87.90	A
Bactomix	243.00	71.65	29.49	95.80	442.00	110.90	B

*Differences between variants labelled with the same symbol are not statistically significant ($\alpha = 0.01$).

The bare-rooted variant with Baktomix differs from the control positively in all the evaluated characteristics, except volume and average length the values of which are lower in comparison with the control. These differences, however, are not statistically significant.

Table 3. Comparison of basic statistical characteristics between individual variants, root surface (cm^2)

Variant	Statistical characteristic						
	Mean	s_x	s_x [%]	Min	Max	%	Duncan*
Control	25.48	7.42	29.13	9.16	51.50	100.00	B
Lännen	94.50	28.28	29.93	47.08	156.58	370.90	C
Alginit	21.30	5.30	24.88	11.78	42.02	83.60	A
Bactomix	26.49	7.92	29.89	11.52	52.18	104.00	B

*Differences between variants labelled with the same symbol are not statistically significant (α = 0.01).

Table 4. Comparison of basic statistical characteristics between individual variants, root volume (cm^3)

Variant	Statistical characteristic							
	Mean	s_x	s_x [%]	Min	Max	%	Duncan*	$g\ cm^{-3}$
Control	0.24	0.07	32.58	0.09	0.46	100.00	B	0.22
Lännen	0.89	0.25	28.62	0.42	1.34	375.50	C	0.34
Alginite	0.19	0.05	27.48	0.10	0.42	79.70	A	0.23
Bactomix	0.23	0.07	31.55	0.11	0.51	97.50	B	0.25

*Differences between variants labelled with the same symbol are not statistically significant (α = 0.01).

Table 5. Comparison of basic statistical characteristics between individual variants, root diameter (mm)

Variant	Statistical characteristic						
	M	s_x	s_x [%]	Min	Max	%	Duncan*
Control	0.37	0.02	6.32	0.32	0.44	100.00	A
Lännen	0.79	0.22	28.25	0.33	1.22	212.60	B
Alginite	0.35	0.03	8.81	0.31	0.53	94.90	A
Bactomix	0.35	0.02	5.88	0.30	0.42	93.30	A

*Differences between variants labelled with the same symbol are not statistically significant (α = 0.1).

Table 6. Comparison of basic statistical characteristics between individual variants, root mass (g)

Variant	Statistical characteristic						
	Mean	s_x	s_x [%]	Min	Max	%	Duncan*
Control	0.05	0.02	31.00	0.02	0.11	100.00	AB
Lännen	0.30	0.08	25.68	0.15	0.43	584.30	C
Alginite	0.04	0.01	27.65	0.02	0.08	84.30	A
Bactomix	0.06	0.02	30.91	0.01	0.11	111.80	B

*Differences between variants labelled with the same symbol are not statistically significant (α = 0.01).

Table 7. Comparison of basic statistical characteristics between individual variants, number of root tips (n)

Variant	Statistical characteristic							
	Mean	s_x	s_x [%]	Min	Max	%	Duncan*	$n\ cm^{-1}$
Control	720.00	234.50	32.58	224.00	1660.00	100.00	A	3.30
Lännen	2,702.00	1,052.87	38.96	1,242.00	5,700.00	375.30	B	3.40
Alginite	687.00	269.40	39.20	280.00	2591.00	95.40	A	3.60
Bactomix	737.00	244.90	33.22	211.00	1731.00	102.40	A	3.00

*Differences between variants labelled with the same symbol are not statistically significant (α = 0.01).

Table 8. Basic values of one-way variance analysis with block experiment for each variant

Source of variability	df	F	p
Length (cm)	3	48.3	0.0001
Surface (cm^2)	3	59.2	0.0001
Volume (cm^3)	3	76.7	0.0001
Mean diameter (mm)	3	1,007.0	0.0001
Weight (g)	3	162.7	0.0001
Root tips number (n)	3	67.5	0.0001
For all variants	block 2, residuum 344		

Discussion

Comparing the growth of root system between the bare-rooted and ball plants we can see that the potted material was significantly better than the bare-rooted in all the evaluated quantitative characteristics. Šmelková and Tichá (2003) report for an experiment with larch the mean root dry weight obtained in variant Lännen representing 145% of dry weight obtained with bare-rooted seedlings. Similar results also reached Tichá (2004) studying spruce seedlings grown in mineral soil and in pots Jiffy 7 Forestry™. In favour of the potted technology, the number of lateral roots being 1.4 times higher than in bare-root technologies gives evidence. The author further reports even a more marked increase – up to four times observed in dry mass of root system of the potted plants. In our experiment (see part *Results*), the difference between the variant Lännen and the control reached almost a value of six.

The lowest mean values of the measured variables (apart from mean diameter) were obtained in the bare-root variant with alginite. This variant is statistically significantly different from the other variants in root system's surface area and volume; in terms of root length and mass, it forms one homogeneous group with the control. The same result also obtained Sarvašová (2006) in her experiment with seedlings of *Abies alba* when she found that the influence of alginite on growth of these seedlings was insignificant in terms of root length and root mass. In experiments with the artificial hydroabsorbent TerraCottem™ coupled with precisely controlled watering, the same author (1999) confirmed for spruce seedlings grown in containers synergic effect of watering and amount of TerraCottem in the substrate in case of all the measured variables, except the aboveground axis. The influence of watering regime was found more pronounced than the influence of amount of the hydroabsorbent.

Takáčová et al. (2006) who carried out experiments with artificial hydroabsorbent Stocksorb Micro™ admixed to substrates used in the Lännen technology, did not observe influence of this substance on growth of aboveground parts of the seedlings. In this case, the differences resulted from differences in photoperiod.

From these results we can conclude that the influence of hydroabsorbents on values of morphological characteristics of the seedlings does not depend on amount of the applied substance only, but also on interactions of these chemicals with other factors – primarily the watering regime, soil type and woody plant species. For this reason, the positive influence of hydroabsorbents is more evident in case of their use at drier and poorer localities. Promising is also their use in protection of root system in transport of and manipulation with planting material. Our results show that in conditions of sufficient water supply, the influence of alginite is rather negative, because most mean values of the evaluated parameters in root systems (not regarding statistical significance of the differences) were the lowest in this variant. The case can be in the water-logged substrate entailing lack in soil oxygen to which the spruce is especially sensitive (Köstler et al., 1968).

Tučeková (2004b) reports the first data obtained in testing the microbiological soil conditioner Bacto-Fil B™. The data show that the weight increment in transplants grown in nursery-beds supplemented with this substance was higher by 100%, the amount of hair roots was higher by 30%. The author, however, gives no information either about roots which were considered as hair roots or about the parameter used in evaluation of these roots´ "richness". The values of root system's length in case of bare-rooted variant grown in the substrate with Baktomix admixture were higher by 10.9%, the values of mass by 11.8% than in the control; on the other hand, the volume reached 97.5% of the control, only. These differences, however, are not statistically significant, and based on the results of the Duncan's test, this variant forms one homogeneous group with the control.

Our experimental material evaluated in this paper does not reach the values of biometric characteristic required for a standard planting material according to the Standard STN 48 2211 (Silviculture, seedlings and plants of forest woody plants). Even in case of the ball plants grown in the variant, the requirements of the Standard have not been met – due to too small diameter of the root collar having had the mean value of 1.219 mm, and the maximum of 2.25 mm.

The obtained results are high reliable and precise, and they can be used with profit in planning the following experiments.

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Vplyv substrátu a technológie pestovania na kvantitatívne charakteristiky koreňových systémov semenáčikov smreka (*Picea abies* (L.) Karst.): porovnanie kvantitatívnych znakov

Súhrn

Táto práca analyzuje vplyv rozlične modifikovaných substrátov a technológie Lännen Plantek na rast koreňových systémov 1-ročných smrekových semenáčikov. Substrát pre voľnokorenné semenáčiky bol vytvorený zmesou rašeliny a kompostu. Doňho bol potom primiešaný bakteriálny prípravok Baktomix® (4 l/m^2) a ílovitý minerál alginit (3 kg m^{-2}). Čistý substrát slúžil ako kontrola. Voľnokorenné sadenice boli porovnávané s krytokorennými vypestovanými technológiou Lännen Plantek. Zisťovali sa nasledujúce parametre: hmotnosť koreňového systému v sušine, dĺžka koreňov, veľkosť ich povrchu, počet zakončení koreňa (koreňových špičiek) a jeho objem. Tieto parametre boli zisťované pomocou programu WinRhizo a následne boli analyzované.

Variabilita jednotlivých hodnôt bola pomerne nízka, pohybovala sa okolo 30 %. Variant Lännen Plantek dosahoval vo všetkých sledovaných parametroch niekoľkokrát vyššie hodnoty ako voľnokorenné semenáčiky. Rozdiely v týchto znakoch medzi samotnými voľnokorennými variantmi boli, aj napriek malým diferenciám v ich hodnotách, väčšinou štatisticky významné, a to vďaka spomínanej nízkej variabilite. Pri biometrických znakoch priemerná hrúbka a počet zakončení tvoria všetky tieto tri varianty homogénnu skupinu, v ostatných hodnotených znakoch patria do rovnakej skupiny Baktomix spolu s kontrolným variantom, alginit s kontrolou pri hodnotách parametrov hmotnosť a dĺžka koreňového systému. Diferencie medzi Baktomixom a alginitom sú signifikantné v hmotnosti, dĺžke, ploche povrchu aj veľkosti objemu. Použitie alginitu pôsobí pri rovnakom závlahovom režime skôr nepriaznivo na rastové schopnosti koreňov, štatisticky významne pri $\alpha = 0,01$ sa od ostatných variantov líši nižšími hodnotami povrchu a objemu koreňa.

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Woodland strawberry (*Fragaria vesca* L.) – growth parameters in the Chočské vrchy Mts

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Abstract

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The research was oriented on study of variability of selected growth parameters (length, weight, energy content, number of leaves in rosette and content of plant ash) of woodland strawberry in ecologically different geobiocoenoses in the Chočské vrchy Mts. The studied geobiocoenoses belong to the follo-wing forest vegetation tiers: the 4th – beech (geobiocoenosis 8), the 5th – fir-beech (geobiocoenoses 1, 5 and 6) and the 6th – spruce-beech-fir (geobiocoenosis 2). The highest differences in weight and energy storage of the *Fragaria vesca* rosettes (58%) were found between the geobiocoenoses of the 5th and the 6th forest vegetation tiers. The differences in energy density [kJ g^{-1} of dry matter] were small (3.2%), and significantly lower values were observed in the geobiocoenosis of the beech vegetation tier, similarly as in case of rosette length. The differences in the length and number of leaves in rosettes reached 33–34%. The highest average number of leaves per one rosette was ascertained in geobiocoenosis of the beech vegetation tier, the lowest in spruce-beech-fir vegetation tier. Significantly higher growth parameters (the mean length, weight, ash and energy content) of woodland strawberry observed in forest geobiocoenoses of 5th vegetation tier were connected with lower total herb cover.

Key words

Fragaria vesca L., growth parameters, forest ecosystems, the Chočské vrchy Mts

Introduction

The Chočské vrchy Mts are characterised by a considerable diversity of forest ecosystems represented by geobiocoenoses from the 4th (beech) to the 8th (dwarf pine) forest vegetation tiers (fvt). The current altitudinal gradation of vegetation is a result of long-term interrelations between the climatic conditions and ecological requirements of the plant species. The differences in ecological conditions are caused especially by mesoclimate and altitudinal climate, which is primarily reflected in composition of woody species and secondary also in herb layer of the biocoenoses (Hančinský, 1972). The high diversity of the plant species results from the specific properties of soils formed from carbonate parent rocks and variable geomorphological and climatic conditions. Growth and development of plants are influenced very significantly also by abiotic stress factors, eg by occurrence of extreme temperature, drought, environment pollution, etc (Bláha and Hnilička, 2004). The rate of energy flow, nutrient cycling, primary production and decomposition of organic matter are controlled by climatic, primarily temperature- and moisture-related environmental conditions. Therefore knowledge of developmental state of forest ecosystems is not possible without systematic study of their ecological conditions as well as of succession processes and changes in growth parameters of the species populations forming the plant communities (Kukla et al., 2003, 2004; Kuklová et al., 2005; Barna, 2000, 2004; Kodrík, 2004). In this paper we present results of research primarily oriented on assessment of growth parameters of the woodland strawberry (*Fragaria vesca* L.) currently growing in ecologically different ecosystems of the 4th and 6th forest vegetation tiers in the Chočské vrchy Mts.

Material and methods

The Chočské vrchy Mts belong to the territory of West-Carpathian flora, district Central Carpathians, region Fatra and sub-region Chočské vrchy. The vegetation cover has mountain to high-mountain character. The geological substrate consists of mesozoic rocks as carbonates, dolomites and clay-rich limestones (Michal, 1977; Bozalková, 1981). In general, the Chočské vrchy Mts belong to moderately cold and cold climatic regions (Šamaj and Valovič, 1981).

The research was carried out in ecologically different geobiocoenoses selected on the background of forest typological maps and terrain recognition. The selecting criterion was phytocenological uniformity and sufficient size of geobiocoenological plots. The research of the *Fragaria vesca* population was carried out on five monitoring plots situated at altitudes 710–800 m. The studied geobiocoenoses belong to the 4th – beech (geobiocoenosis 8), 5th – fir-beech (geobiocoenoses 1, 5 and 6) and 6th – spruce-beech-fir fvt (geobiocoenosis 2). More detailed characteristic of the geobiocoenoses is presented in Table 1. The soils were classified according to Collective (2000), the geobiocoenoses in sense of Zlatník (1976a, b) and the plant taxa were determined and named according to Dostál (1989).

The plant material was obtained by means of random sampling from an area of 400 m^2 of the phytocoenological relevé. The *Fragaria vesca* species as a typical rosette plant is characterised by the clonal growth form (Klimeš et al., 1997). As a plant individual was considered rosette of leaves. The following phytoparameters were measured: the number of leaves in rosette, length of the longest shoot, and after drying at 80 °C for 48 hours, the weight of rosette with a precision of 0.002 g. The samples were homogenised in a planetary micro mill (<0.001 mm) and amounts weighing 0.7–1 g were pressed into a form of briquette, dried at 105 °C, to a constant weight and burnt in pure oxygen under a pressure of 3.04 MPa. The energy value of shoots was determined using an adiabatic calorimeter IKA C 4000 (C-402 software). The content of ash was determined gravimetrically, after burning the plant sample in a muffle furnace at 500 °C (Javorský et al., 1987).

The influence of ecological conditions on the growth parameters of the strawberry was evaluated by using the method ANOVA and the Mann-Whitney U test.

Table 1. Basic characteristics of the studied geobiocoenoses

Geobiocoenosis		G5	G1	G6	G2	G8
Altitude [m]		800	730	780	780	710
Exposition		ENE	NW	NNW	NW	S
Slope [°]		25	10–15	30	30–35	35–40
Rock		clay-rich limestone	dolomitic limestone			
Soil		Eutric	Calcaric		Cambi-Rendzic	Rendzic
		Cambisol			Leptosol	
Forest vegetation tier		5. fir-beech			6. spruce-beech--fir	4. beech
Edaphic-hydric	order	leading			a little restricted	restricted
	suborder	normal	on shallow or skeletal eluvium			dwarfish
Edaphic-trophic order/interord.		B	B/D		C/D	D
		mesotrophic	mesotrophic/calc.		nitrophilous/calc.	calciphilous
Group of types of geobiocoens (Zlatník, 1976a, b)		*Abieti-Fageta typica*	*Abieti-Fageta ulmi inferiora*		*Fagi-Acereta superiora*	*Pineta dealpina*
Stand age [year]		80–100	80–100	80–100	50–70	40–80
Stand density		0.7–0.8	0.7–0.8	0.6	0.5–0.6	0–0.6
Canopy [%]		80	80	70	60^{40}	0–60
Total herb cover [%]		70–90	60–90	60–80	80–100	80–90
Grasses and grassy species [%]		10^{30}	20–40	5–10^{70}	10–20^{40}	20–70
The other species [%]		60–80	40–70	40–60	70–90	30–60
Mosses [%]		5–10	15–20	10^{30}	80	–

Results and discussion

Number of leaves in a rosette

The average number of leaves found in strawberry rosettes (Table 2) ranged from 3 to 4.5 (minimum – 2 leaves, maximum – 7 leaves in a rosette). According to the decreasing mean number of leaves in a rosette, the studied geobiocoenoses (G) can be arranged into the following order: G8 (4.5) > G6 (4.4) > G1 (4.1) > G5 (3.9) > G2 (3.0). The maximal number of leaves in a rosette (4.5) was observed in the 4th – beech fvt, the lowest (3) in the 6th – spruce-beech-fir fvt (geobiocoenosis G2). The number of leaves in a rosette showed differences between the plots. There were found significant differences among strawberry population growing in geobiocoenosis G2 in comparison with populations growing in other geobiocoenoses (Table 3; $P < 0.01$; Mann-Whitney U test).

Length of a rosette

The length of rosettes (of the longest leaf) of woodland strawberry is presented in Fig 1. The average length of rosettes ranged from 9.9 cm to 14.9 cm. According to the descending length of rosettes (mean ± standard deviation), the studied geobiocoenoses create the following sequence: G1 (14.9 ± 2.6 cm) > G5 (14 ± 2.2 cm) > G2 (13.4 ± 2.1 cm) > G6 (10.7 ± 1.8 cm) > G8 (9.9 ± 2.4 cm). Higher values of this parameter were observed in geobiocoenoses of the 5th and 6th fvt (G1, G2 and G5). The maximum difference in length of rosettes reached 5 cm and the minimum length represented 66% from the maximum one. Significant differences (Tables 4, 5) were found among average rosette lengths of strawberry population growing in geobiocoenosis of beech fvt and the populations growing in the geobiocoenoses situated in the fir-beech and spruce-beech-fir fvt ($P < 0.01$; LSD multiple range test). The mean lengths of strawberry rosettes found in the Chočské vrchy Mts are comparable with the mean rosette lengths of this species (7.4–15.2 cm) found in phytocoenoses of managed beech stands in the Kremnické vrchy Mts by Schieber and Kováčová (2002a). Longest strawberry rosettes (17.4 cm) observed these authors in a closed beech stand with the lowest intensity of penetrating light (Schieber and Kováčová, 2002a).

Weight of a rosette

The average dry weight of strawberry rosettes growing in the phytocoenoses of the studied geobiocoenoses ranged from 0.200 to 0.345 g (Fig 1). The minimum weight represents 42% from the maximum one. According to decreased weight of rosettes (mean ± standard deviation), the studied geobiocoenoses create the following sequence: G1 (0.345 ± 0.068 g) > G5 (0.301 ± 0.069 g) > G8 (0.297 ± 0.022 g) > G6 (0.214 ± 0.036 g) > G2 (0.200 ± 0.067 g). Significantly higher weight of rosettes was observed in geobiocoenosis G1 (5th fvt) in comparison with populations growing in geobiocoenoses G2 (6th fvt) and G6 (5th fvt; $P < 0.05$; LSD multiple range test; Table 4, 5). The mean weight of strawberry rosettes found in the Chočské vrchy Mts is comparable with the mean weights of this species (0.134 to 0.338 g) found in the phytocoenosis of a closed managed beech stand in the Kremnické vrchy Mts (Schieber and Kováčová, 2002a). Somewhat higher values (by 19–51 %) observed these authors in case of fertile strawberry individuals (Schieber and Kováčová, 2002b).

Table 2. Mean number of leaves in *Fragaria vesca* rosettes

Geobiocoenosis	Sample size	Average	Minimum	Maximum	Standard deviation	Coefficient of variation
G1 (5th fvt)	21	4.1	2	6	±0.99	24.3
G2 (6th fvt)	20	3.0	2	4	±0.73	24.2
G5 (5th fvt)	21	3.9	2	5	±0.72	18.8
G6 (5th fvt)	35	4.4	2	7	±1.15	25.6
G8 (4th fvt)	18	4.5	3	6	±0.70	15.9

Table 3. Statistically significant differences in number of rosette leaves of *Fragaria vesca* species (* $P < 0.01$; Mann – Whitney U test)

Geobiocoenosis	G1 (5th fvt)	G5 (5th fvt)	G6 (5th fvt)	G8 (4th fvt)
G2 (6th fvt)	0.00070*	0.00085*	0.00001*	0.000009*

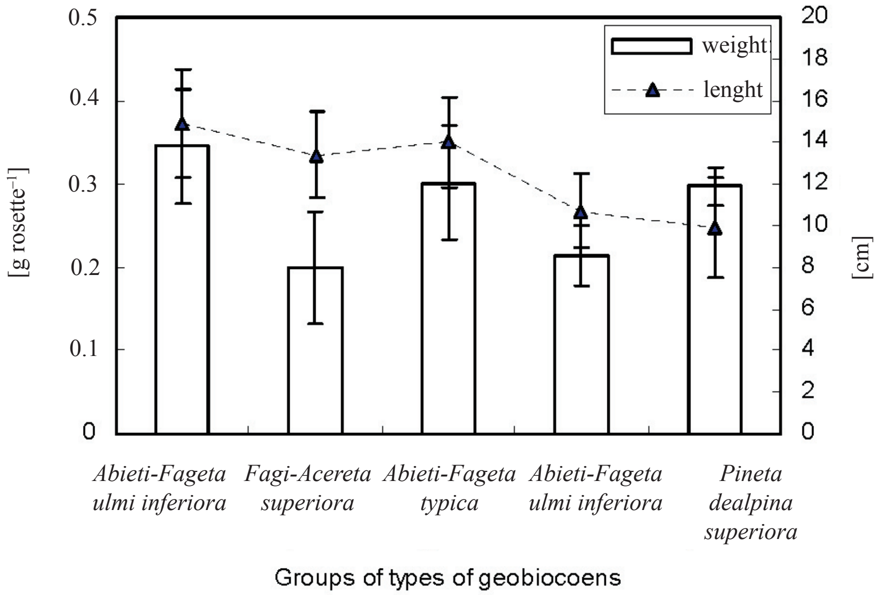

Fig 1. Dry weight and length of long leaf in *Fragaria vesca* rosettes (mean ± standard deviation)

Table 4. Results from one way ANOVA of Fragaria vesca growth parameters (* P < 0.05; ** P < 0.01)

Growth parameter	ANOVA			Bartlett´s test
	Degrees of freedom	F-ratio	P-value	
Rosette length	4; 114	21.050	0.0000**	0.4808
Rosette weight	4; 19	4.864	0.0102*	0.3781
Energy content	4; 19	8.668	0.0008**	0.1226

Table 5. Statistically significant differences in growth parameters of *Fragaria vesca* rosettes (*P < 0.05, **P < 0.01, LSD multiple range test)

Geobiocoenosis	G1 (5th fvt)	G2 (6th fvt)	G5 (5th fvt)	G6 (5th fvt)	G8 (4th fvt)
			Length		
G6 (5th fvt)	**	**	**	–	ns
G8 (4th fvt)	**	**	**	ns	–
			Dry weight		
G1 (5th fvt)	–	*	ns	*	ns
			Energy density		
G8 (4th fvt)	**	**	**	**	–

Energy and ash content in a rosette

The energy content (Joul g^{-1} d.m.) and energy storage (Joul $rosette^{-1}$) in strawberry rosettes are illustrated in Fig 2. According to the descending energy content (mean ± standard deviation) the studied geobiocoenoses create the following order: G1 (18,533 ± 42.5 J g^{-1}) > G2 (18,469 ± 102 J g^{-1}) > G6 (18,407 ± 126 J g^{-1}) > G5 (18,357 ± 204 J g^{-1}) > G8 (17,934 ± 244 J g^{-1}). Density of energy in 1 g of dry matter was different (Tables 4, 5). Maximum difference among the studied geobiocoenoses made 599 J. Significantly higher density of energy was observed in geobiocoenoses of the 5th and 6th fvt (G1, G2, G5 a G6) in comparison with geobiocoenosis G8 situated in the 4th fvt (P < 0.01; LSD multiple range test). The results are comparable with the data (18,220–21,352 J g^{-1} d.m.) obtained in other regions of the West Carpathians (Kováčová and Schieber, 2003; Kukla et al., 2003; Kuklová et al., 2005; Konôpková and Tokár, 2000; Konôpková, 2006).

The ash content found in the strawberry rosettes growing in the Chočské vrchy Mts fluctuated from

8.2% to 10.8%. The maximum value of the ash content in this species was found in the geobiocoenosis G1 (5th fvt).

Conclusions

The obtained results show that growth parameters of the *Fragaria vesca* species growing in the geobiocoenoses situated from the 4th to the 6th fvt are considerably variable. The highest differences among the studied strawberry populations (about 58%) were found in the values of dry weight and energy storage of rosettes. However, the significant differences were found only between the geobiocoenoses of the 5th and 6th fvt. The differences in density of energy were not big (3.2%). Significantly higher density of energy was observed in the ecosystems situated in the 5th and 6th fvt in comparison with the 4th fvt. The differences in length of rosettes and number of leaves in strawberry rosettes represented 33–34%. Significantly higher length of rosettes was ascertained in geobiocoenoses situated in the 5th and 6th fvt in comparison with the geobiocoenosis of 4th fvt. The highest average number of leaves in rosette was found in the geobiocoenosis of beech vegetation tier, the lowest in geobiocoenoses of spruce-beech-fir vegetation tier. Significant differences in number of rosette leaves were found among strawberry populations growing in the 6th fvt and populations growing in other studied geobiocoenoses. Significantly higher growth parameters (the mean length, weight, ash content and content of energy) of woodland strawberry observed in geobiocoenoses of 5th fvt were associated with lower total herb cover of plant communities.

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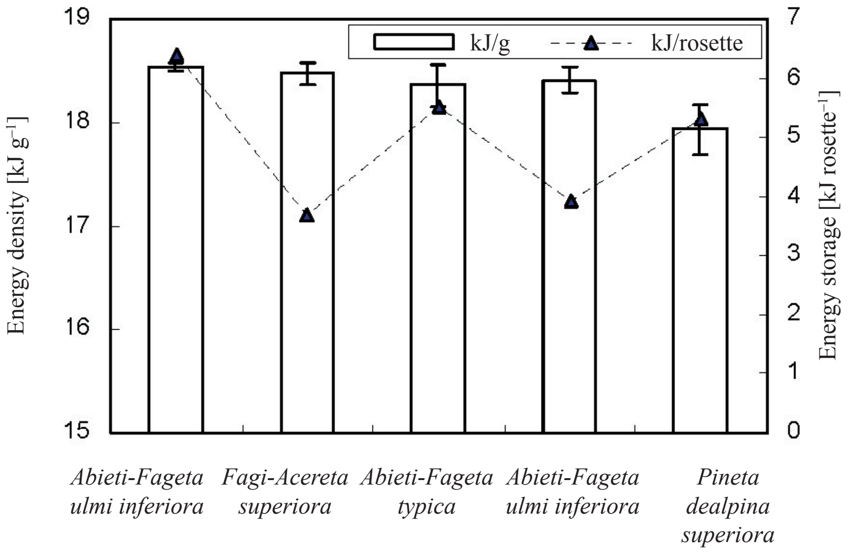

Fig 2. Content of energy in dry mass of *Fragaria vesca* species (mean ± standard deviation)

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Rastové parametre jahody obyčajnej (*Fragaria vesca* L.) v Chočských vrchoch

Súhrn

Výskum bol zameraný na štúdium variability vybraných rastových parametrov (dĺžka, hmotnosť, obsah energie, počet listov v ružici a obsah popola) jahody obyčajnej v ekologicky rozdielnych geobiocenózach Chočských vrchov. Skúmané geobiocenózy patrili do nasledovných lesných vegetačných stupňov: 4. bukový (geobiocenóza 8), 5. jedľovo-bukový (geobiocenózy 1, 5 a 6) a 6. smrekovo-bukovo-jedľový (geobiocenóza 2). Najväčšie rozdiely v hmotnosti a zásobe energie v ružiciach druhu *Fragaria vesca* (58 %) sa zistili medzi geobiocenózami 5. a 6. lesného vegetačného stupňa. Rozdiely v hodnotách energie [kJ g^{-1} sušiny] boli malé (3,2 %) a významne nižšie hodnoty sa zistili v geobiocenózach bukového vegetačného stupňa, podobne ako v prípade dĺžky ružíc. Rozdiely v dĺžke a počte listov v ružiciach dosiahli 33–34 %. Najvyšší priemerný počet listov v ružici sa zistil v geobiocenóze bukového vegetačného stupňa, najnižší v smrekovo-bukovo-jedľovom vegetačnom stupni. Významne vyššie rastové parametre (priemerná dĺžka, hmotnosť, obsah popola a energia) jahody obyčajnej zistené v lesných geobiocenózach 5. vegetačného stupňa súviseli s nižším celkovým krytom bylín.

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Root system emergence and health condition in Norway spruce (*Picea abies* (L.) Karst.) affected by yellowing of assimilatory apparatus in the region of the Krušné hory Mts

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Abstract

Mauer, O., Palátová, E., Pop, M. 2008. Root system emergence and health condition in Norway spruce (*Picea abies* (L.) Karst.) affected by yellowing of assimilatory apparatus in the region of the Krušné hory Mts. *Folia oecol.*, 35: 39–50.

The paper analyses the decline of Norway spruce stands over a region operated by the Forest Administration in Horní Blatná (Krušné hory Mts) and its causes. Root system analyses made in 238 trees (age 10–117 years, Forest Altitudinal Vegetation Zones 6 and 7, modal podzol) showed that all trees affected by yellowing of their assimilatory apparatus had a smaller root system, worse root pattern distribution, root systems malformed into a tangle, smaller rooting depth and lower biomass and vitality of fine roots. Until an age of about 10 years, trees at good health condition are those, which have created a large superficial root system. From an age of about 20 years, healthy trees are those, which have created a large anchoring root system with anchors reaching into the Bs horizon. Impaired vitality induced in affected trees invasion of the honey fungus causing the infestation of individual root system branches (namely anchors), and reducing the size and hence the functionality of the root system.

Keywords

rots, decline, root system, Norway spruce, yellowing of assimilatory apparatus

Introduction

Depositions of sulphur and nitrogen compounds in the last several decades of the 20th century that caused the large-scale decline of spruce stands in Central Europe induced changes to soil environment, which affect the vitality and growth of forest tree species for a long time. Many authors observed that soil environment acidification results in changes root distribution within the soil profile. Extremely flat root systems in the Norway spruce were described by Murach (1984, 1991), Raspe et al. (1989), Raspe (1992), Manderscheid and Matzner (1996) and by others. Studying root plates after a storm gale in 1991, Eichhorn and Grabowski (1991) found numerous dying or dead anchor roots protruding from the vital root system and bearing no fine roots. The authors assume that the rot on deep lying roots is induced by chemical stress in the soil. The dieback of anchor roots in old rowan trees in the Krušné hory Mts was reported by Palátová and Mauer (2002), too. In spruce stands aged 40 years, which essentially differed in soil conditions (saturation with bases) as well as in the degree of damage (yellowing of needles, defoliation), Fritz et al. (2000) detected a distinct vertical gradient of the density both live and dead fine roots with a conspicuous concentration of fine roots in the humus layer and the situation was most striking in localities with the lowest degree of saturation with bases. Similarly, Hruška and Cienciala (2001) inform that in acidified soils, a greater part of the root system is localized in organic horizons with only a minimum amount of roots reaching into mineral soil.

The withdrawal of fine roots from deeper horizons to the upper soil or forest floor induced by soil acidification and imbalanced nutrient contents may increase the danger of exposure to biotic and abiotic factors, drought in particular (Wolf and Rickli, 1987; Ulrich, 1987; Eichhorn and Grabowski, 1991). Climatic extremes (extreme drought, high insolation or high temperatures) represent stress factors for trees, which may also lead to impaired vitality and to a visible manifestation of damage symptoms (Dittmar et al., 2004). Apart from affecting the growth and production of above-ground biomass, namely the lack of water may affect the root system, too (Bartsch, 1987; Feil et al., 1992).

Changes in the amount, distribution and functionality of fine roots may impair the tree vitality due to limited supplies of nutrients and water. Tree nutrition and water regime may also be disturbed by root systems malformed due to incorrect technology of planting stock cultivation, improper planting methods or careless work. Deformations may affect either individual branches of the root system or the root system as a whole. The most serious root system malformation is considered to be a so called tangle (root coiling) because the mutual strangulation of horizontal roots induced by their swelling may restrain not only their conductive function (Sauer, 1984; Mauer, 1989, 1999; Jurásek and Martincová, 2001; Mauer and Palátová, 2004) but also the tree infestation by parasitic fungi, namely honey fungus (Mauer, 1989; Jurásek and Martincová, 2001).

The monitoring of air pollution corroborates that in the last decade a significant reduction occurred in the deposition of sulphates and a milder reduction was recorded also in the emissions of nitrogen oxides and hydrocarbon compounds. On the other hand, ozone concentrations remain high, only the number of days with high ozone concentrations has significantly decreased (Wienhaus, 2003). After the change of the emission situation, the condition of Norway spruce stands in the Czech Republic markedly improved. However, after the period of certain optimism, the forestry practice has to face another problem. The decline and dieback of spruce stands occur again, over this time having regional character, usually a distinctly demarcated territory, with the symptoms and course of decline often varying from region to region. In the western Krušné hory Mts, some stands of Norway spruce were recently affected by assimilatory apparatus yellowing and by subsequent defoliation. The injury appeared in stands of all age classes on a total forest area of 9,000 hectares. The goal of the study was to contribute to the identification of causes to the damage that would facilitate the implementation of efficient forest management measures.

Material and methods

The primary objective of the survey was to compare emergence and health condition in Norway spruce trees of identical height affected by yellowing (with defoliation or changed colour of assimilatory apparatus 40–60%) and healthy trees (with no visual symptoms of injury, possibly with a defoliation or changed colour of assimilatory apparatus up to 10%), growing in the same stand. The procedure could not be adhered to in Stand 64 because there were no longer healthy trees in it, and therefore an intact stand of the same age growing on the same site was chosen as a control. To be able to assess whether the injury occurs only in artificially established stands, the analyses included also the stands from natural regeneration. With the aim to find out the influence of liming on the emergence and health condition of the root system, the analyses included six limed and six unlimed stands growing very close one to another on the same site, aged from 42 to 117 years. Liming with dolomitic limestone was applied in years 2001 and 2003 at a dose of 3 t ha^{-1}. With respect to the fact that the effect of liming could not reflect on the root system architecture, only fine roots were analyzed in these stands. All analyzed stands were monocultures of identical stocking, growing on the flat ground or the mild slope (gradient up to 5%). Selected for analyses were only trees in the main level, undamaged by game and non-marginal, with an identical above-ground part height. Characteristics of the analyzed stands are presented in Table 1.

Table 1. Characteristics of analyzed forest stands

Stand number	Stand designation	Soil type	Forest type	Altitude [m asl]	Age	Air-pollution danger zone
2D1	14 healthy, 14 injured+	modal podzol	7K3	940	14	B
122A2/1a	13 healthy, 13 injured	modal podzol	6K1	900	13	C
2A1	10 healthy, 10 injured	modal podzol	7M3	890	10	C
1E2/1b	20 healthy, 20 injured	modal podzol	7M3	940	20	B
119A2	19 healthy, 19 injured	modal podzol	7M3	880	19	C
120A3	30 healthy, 30 injured	modal podzol	6M3	820	27	C
1B3	26 healthy, 26 injured	modal podzol	7M3	960	26	B

Table 1. Continued

Stand number	Stand designation	Soil type	Forest type	Altitude [m asl]	Age	Air-pollution danger zone
121B4	40 healthy, 40 injured	modal podzol	6K1	880	40	C
17A6	64 injured	modal podzol	7K3	900	64	C
108D6	64 healthy	modal podzol	7K3	900	63	C
121B6	64 healthy, 60 injured	modal podzol	7K3	860	59	C
120A6	Self-seeding smaller healthy, Self-seeding smaller injured	modal podzol	6K1	780		C
120A6	Self-seeding larger healthy, Self-seeding larger injured	modal podzol	6K1	780		C
102A4	40 liming (in 2003)	modal podzol	7M3	910	42	C
14E4	40 no liming	modal podzol	7M3	930	45	C
102A6	60 liming (in 2003)	modal podzol	7M3	910	63	C
14E7	60 no liming	modal podzol	7M3	920	71	C
118A12	100 liming (in 2001)	modal podzol	7M3	920	117	B
107B10	100 no liming	modal podzol	7M3	920	97	B

Analyses of root system architecture and health condition

All root systems were lifted by hand (the archaeological method). A minimum number of trees analyzed at all times in stands aged up to twenty years was 12. A minimum number of trees analyzed in stands aged 20 and more years was 6 (both healthy and injured). The effect of liming was studied in six stands aged 42–117 years. The total number of analyzed trees was 238.

Parameters measured and assessed in all trees were as follows: total height of above-ground part (from the ground to the end of terminal increment), stem diameter $d_{1.3}$, length of terminal shoots in 2004 and 2005, root system malformation into tangle, number and diameter of horizontal skeletal roots (diameter was established at 20 cm from the trunk in ten and twenty-year old trees, at 40 cm from the trunk in thirty-year old trees, and at 60 cm from the trunk in sixty-year old trees), number and diameter of anchoring roots (diameter was measured at 5 cm from the point of setting). Measured values were used to calculate the area index (hereinafter Index p, in Table of results Ip) to express relation between the root system size and the size of above-ground part. It was calculated as the ratio of cross-sectional areas of all horizontal skeletal roots and anchoring roots (anchors) at the point of measurement in square milimeters to the length of above-ground part of trees in centimeters. The greater the Index p value, the larger the tree root system. Rooting depth in the corresponding soil horizons was measured as a perpendicular distance from the soil surface to the tip of the anchoring root. The length of horizontal skeletal roots was measured from the stem base to their end. Regularity of the distribution of horizontal roots in the root network was assessed according to the maximal angle between the two outermost horizontal skeletal roots.

All lifted root systems were visually inspected for the occurrence of honey fungus according to resin exudations. Root rots were established from the longitudinal sections of all roots, stem rots were established from stem cross-sections. Regarding the fact that the root systems were affected by rots, some partial traits (Index p, rooting depth) were established separately both for the whole root system, and for the functional part of the root system, ie for the root system part not affected by rots (in tables as "Whole root system" and "Functional root system"). Fine roots (<1 mm) were sampled so that 30 soil cores were lifted from each analyzed stand (separately for healthy and injured trees) with a soil sampler of 5 cm in diameter. The cores were subsequently divided according to the soil horizons and homogenized. Surveyed were all humus horizons (Humus) and the mineral layer 0–10 cm under the humus horizons (Mineral). From each homogenate, six samples were taken for analysis, each of 100 ml (apparent volume). After separation and additional manual cleaning, the fine roots were desiccated and their biomass was established. In the stands aged 60 and 40 years, the biomass of fine roots was established in the entire rooting profile of anchors.

In all analyzed stands, 5 soil monoliths 20 × 20 cm were sampled from the humus horizons (separately for healthy and injured trees), from which fine roots were removed manually, cleaned and homogenized. The fine roots obtained in this way were assessed for their vitality by using the method of 2,3,5 triphenyltetrazolium chloride reduction (Joslin and Henderson, 1984). Results from the processing of the samples were subjected to correlation analysis and the vitality was calculated in percent. Mycorrhizal infection was established quantitatively by chemical methods described by Plassard et al. (1982) and Vignon et al. (1986). The type of mycorrhiza was assessed anatomically after staining the fungus with aniline blue in lactophenol. Morphological structure of the mycorrhiza was assessed visually by using a stereo-magnifying glass.

Tables of results present arithmetic means of the respective parameters and their standard deviations. Significance of results was tested by T-test at a significance level of 95%; test results are in the tables of results plotted graphically (+ significant variance, – insignificant variance).

Results

Analyses of root system architecture and health condition

The comparison of healthy and injured trees standing one close to another revealed that all analyzed injured trees lagged behind the healthy trees in the length of their terminal increment (Table 2), their root system being smaller and the number and diameter of their skeletal roots (both horizontal and anchors) being lower. This was markedly reflected in lower Index p values for the Whole root system (Table 3a and 3b). The healthy and injured trees did not differ in the length of their horizontal skeletal roots.

As compared with the healthy trees, all analyzed injured trees showed a shallow root system, lower number and diameter of anchoring roots and distinctly reduced rooting depth. The injured trees exhibited a worse distribution of root network (greater maximal angle between horizontal skeletal roots, Table 3a). With an exception of trees from self-seeding, all analyzed injured trees exhibited the most serious root system malformation – tangle, which occurred, however, in most healthy trees, too (Table 3b). Honey fungus occurred in all injured trees and in nearly all healthy trees with a greater number of infected roots detected in the injured trees than in the healthy trees (Table 2). In some older injured trees, the honey fungus evoked root rots. Other parasitic fungi were not found on the root systems or on the tree stems (analyzed were only trees undamaged by game).

The above evaluation might suggest a conclusion that injured trees are those with a lower rooting depth or with a lower Index p of the Whole root system. A mutual comparison of all healthy and injured trees of approximately the same height (eg smaller self-seeding and stand 10, stand 60 and stand 64, stand 30 and stand 26) indicates, however, that the dependence does not hold entirely because rooting depth or Index p of the Whole root system may be in a healthy stand lower than in an injured stand. Index p of the Whole root system in the injured trees is markedly affected by the honey fungus. If we calculate Index p values only for the Functional root system (with the calculation including only roots not affected by the honey fungus), and if we put into relation the rooting depth and the rooting within the soil horizons, we shall see that in the stands aged up to about ten years, the trees create mostly a

Table 2. Biometric parameters of the above-ground part and honey fungus incidence

Stand designation	Above-ground part length [cm]	Terminal increment [cm]		Honey fungus incidence	
				Number of affected trees	Number of affected roots
		2004	2005	[in %]	[pcs tree^{-1}]
14 healthy	428±48	46.8±8.2	47.8±9.4	100	1.8±1.3
14 injured	375±56	32.2±6.1+	45.4±8.4-	100	3.4±0.9+
13 healthy	389±11	64.7±9.5	61.3±2.3	100	2.0±0.7
13 injured	328±28	47.3±2.5+	43.0±6.8+	100	4.7±0.6+
10 healthy	307±29	55.3±16.1	53.0±10.7	100	1.5±0.7
10 injured	318±34	25.0± 4.1+	38.0± 6.6+	100	2.6±0.7+
20 healthy	517±71	71.2± 9.5	61.6±17.5	100	2.0±0.6
20 injured	458±30	54.2±10.4+	61.2±7.6-	100	3.4±1.8+

Table 2. Continued

Stand designation	Above-ground part length [cm]	Terminal increment [cm]		Honey fungus incidence	
				Number of affected trees	Number of affected roots
		2004	2005	[in %]	[pcs tree^{-1}]
19 healthy	814±48	47.0±6.1	47.0±2.0	66	1.7±0.6
19 injured	732±68	33.0±9.5+	31.0±8.4+	100	4.6±0.6+
30 healthy	926±57	86.6±2.9	64.3±9.8	0	0
30 injured	935±81	57.5±3.5+	59.0±2.4–	100	4.1±1.2
26 healthy	835±49	85.5±16.2	87.5±3.5	100	1.3±0.6
26 injured	710±14	55.5± 6.4+	80.0±14.4–	100	3.3±1.4+
40 healthy	1,683±157	36.6±9.8	51.5±9.5	100	11.5±4.2
40 injured	1,508±118	16.7±7.9+	46.2±11.2–	100	14.9±2.9–
64 healthy	2,079±127	42.8±5.5	32.0±6.2	100	4.6±0.9
64 injured	1,832±140	31.5±5.9+	22.5±12.5–	100	6.3±2.3–
60 healthy	2,008±119	41.7±12.4	46.2±4.9	100	3.7±0.6
60 injured	1,805±153	27.2±3.2+	29.7±8.4+	100	11.8±5.8+
Self-seeding smaller healthy	306±24	52.6±14.2	52.7±9.2	100	1.8±0.8
Self-seeding smaller injured	259±26	25.3±4.2+	24.0±3.7+	100	5.0±2.8+
Self-seeding larger healthy	796±51	45.6±7.1	49.2±3.6	100	2.8±0.9
Self-seeding larger injured	645±17	7.3±2.2+	16.5±4.1+	100	7.3±0.6+

superficial root system; healthy trees are those with a larger root system. In the stands aged from approx. 20 years, the trees develop mainly an anchoring root system; healthy trees are those with the anchoring and at the same time larger functional root system. As to the rooting depth, it is not the depth itself that is important but the fact whether the anchors reach into the Bs horizon; healthy trees are those whose anchors reach the Bs horizon (Table 3b).

Analyses of fine roots

In the analyzed soil horizons (Humus, Mineral), no essential differences were found between the healthy and injured trees in the biomass of fine roots. However, the healthy trees showed a conspicuously higher occurrence of anchoring roots that further branch into fine roots in the upper part of Bs horizon. The injured trees showed lesser anchoring roots whose branching was minimal. By an additional survey in stands 40 healthy, 40 injured, 60 healthy and 60 injured we found out that in the healthy trees, there are further 70–80% of the biomass of fine roots (100% fine roots biomass in horizons Humus + Mineral into a depth of 10 cm), the amount of which under the horizons of injured trees does not exceed 7%. In both healthy and injured trees, a greater part of fine roots in the Humus horizon occur in its upper part. No differences in the mycorrhizal infection were found between the healthy and injured trees. All injured trees have a markedly worse vitality of the fine roots than the healthy trees (reduced by up to 50%). Liming did not affect the biomass of fine roots or their mycorrhizal infection but increased the vitality of fine roots (Table 4).

Table 3a. Root system architecture

Stand designation	Horizontal skeletal roots		Max. angle between horiz. skeletal roots	Anchoring roots		Average diameter*
	Number	Average diameter		% of trees with anchors	Number*	
	[pcs]	[mm]	[degrees]		[pcs]	[mm]
14 healthy	12.0±5.1	15.6±8.6	64±29	73	1.3±0.8	17.4±5.1
14 injured	12.2±2.7–	9.3±4.3+	110±57+	27	1.5±0.7–	13.3±3.1+
13 healthy	14.3±3.8	13.6±8.3	106±11	100	1.0±0.0	9.3±2.1
13 injured	9.2±0.9+	10.2±4.5+	210±60+	17	2.0±0.0	15.3±1.7+
10 healthy	11.5±4.3	12.6±7.4	110±52	27	2.0±0.6	8.1±2.0
10 injured	7.8±2.1+	8.2±3.6+	132±34–	0	0	0
20 healthy	12.4±1.9	22.0±12.6	70±29	100	3.6±1.5	16.5±6.4
20 injured	9.8±2.1+	13.8±7.9+	112±38+	17	1.0±0.0	29.0±0.0
19 healthy	15.3±2.3	27.6±16.8	40±9	100	7.5±2.1	21.6±8.5
19 injured	12.6±2.1+	18.7±11.9+	82±33+	17	4.0±0.0	25.2±15.1–
30 healthy	11.3±2.5	29.2±18.4	60±28	100	5.3±1.5	32.1±10.1
30 injured	8.5±3.5+	30.8±22.1–	85±21–	100	1.0±0.0	31.0±14.1–
26 healthy	15.5±0.7	18.2±11.1	80±26	100	6.5±4.9	17.3±3.9
26 injured	10.0±1.4+	17.7±9.2–	115±23+	0	0	0
40 healthy	16.2±2.1	42.1±25.9	42±11	100	16.0±4.3	39.1±14.3
40 injured	13.0±2.3+	32.4±13.5+	71±19+	100	12.2±3.1+	36.5±14.2–
64 healthy	16.6±4.1	49.5±26.4	56±11	100	24.1±3.5	39.1±13.3
64 injured	14.2±2.1–	52.5±28.5–	80±20+	100	5.2±1.9+	31.8±11.2+
60 healthy	19.8±1.7	44.3±21.4	38±9	100	17.2±4.3	45.1±16.6
60 injured	13.5±3.1+	40.0±25.8–	77±27+	100	12.7±2.5+	38.0±14.4+
Self-seeding smaller healthy	14.3±3.8	14.1±7.7	68±9	100	5.6±0.6	8.3±1.9
Self-seeding smaller injured	7.5±0.6+	11.7±3.8–	181±2+	100	3.0±1.0+	14.2±2.8+
Self-seeding larger healthy	15.3±2.9	26.8±12.6	73±7	100	7.4±2.7	20.8±7.6
Self-seeding larger injured	8.5±2.1+	17.6±6.9+	145±44+	100	4.5±0.6+	13.7±5.2+

*only in trees with anchoring roots

Table 3b. Root system architecture

Stand designation	Root system deformation into tangle [in % of trees]	Index p Whole root system	Index p Functional root system	Rooting depth [cm]	Roots reaching Horizon Bs
14 healthy	100	8.14±1.01	7.82±0.94	29.8±15.4	no
14 injured	100	3.02±1.40+	2.72±1.46+	20.4±14.2-	no
13 healthy	100	7.56±1.74	7.21±1.64	42.6± 4.1	no
13 injured	100	3.40±0.26+	2.81±0.24+	31.0± 6.0+	no
10 healthy	100	6.82±2.47	6.62±2.25	14.7±9.5	no
10 injured	100	1.75±0.42+	1.43±0.37+	12.6±6.9-	no
20 healthy	100	13.82±4.13	13.11±4.21	38.0± 6.8	yes
20 injured	100	4.46±1.19+	2.97±1.06+	14.8±10.7+	no
19 healthy	100	17.90±0.75	16.94±0.73	72.0±17.6	yes
19 injured	100	7.73±0.13+	5.73±0.31+	24.5± 3.5+	no
30 healthy	67	30.20±5.80	30.20±5.80	84.3± 5.8	yes
30 injured	100	11.20±4.20+	5.53±2.74+	40.5± 9.2+	no
26 healthy	17	8.80±1.55	8.52±1.48	40.0± 4.2	no
26 injured	100	4.35±1.06+	4.08±1.02+	10.0± 2.5+	no
40 healthy	33	34.92±6.30	21.73±5.64	89.6±13.8	yes
40 injured	100	16.77±1.10+	9.51±1.47+	64.0± 6.5+	no
64 healthy	unidentified	33.90±5.05	32.74±5.12	61.4± 9.9	yes
64 injured	unidentified	24.15±5.96+	17.33±4.81+	38.8± 4.4+	no
60 healthy	unidentified	36.53±4.30	34.88±4.17	120.0±23.4	yes
60 injured	unidentified	19.33±5.37+	10.44±4.29+	84.0±19.9+	no
Self-seeding smaller healthy	0	10.21±2.36	10.05±2.53	86.8±14.7	yes
Self-seeding smaller injured	0	5.20±1.55+	3.04±1.36+	40.5± 7.8+	no
Self-seeding larger healthy	0	18.40±1.21	17.55±1.28	86.7±14.9	yes
Self-seeding larger injured	0	4.81±0.84+	2.29±0.72+	59.5±16.3+	no

In spite of the fact that soil conditions of the analyzed stands are heterogeneous, the analyses of chemical and physical characteristics of soil horizons revealed that all injured stands have as compared with the healthy stands less calcium and a critical shortage of magnesium in horizon H, and a critical shortage of phosphorus and more iron in the Bhs horizon. The injured stands have the Humus horizons of lesser thickness, the Bhs horizon more shallowly situated and a greater share of 2–0.25 mm fractions in all horizons (detailed data are available from the authors).

Discussion

The concerned region was not seriously affected by disastrous air pollution at the end of the last century, and currently there are damages belonging to the air-pollution zones B and C. The damage first appeared approximately in 1999 and its intensity varies every year. Some forest stands exhibit large-scale disturbances (with individual trees showing different degrees of damage), which are distinctly individual in some stands (with entirely healthy trees and trees with injuries of up to 80% growing next to one another). The injured trees do not die rapidly (the development of snags is gradual and it is sufficient if these are removed within the framework of planned silvicultural measures). Most damaged are stands on slopes (even mild) exposed to sunlight. All injured stands occur on poor sites (Forest Type Groups 6M, 7M, 6K, 7K).

The implemented analyses unambiguously indicate that the injured trees have a smaller-sized root system and a reduced rooting depth. All analysed stands grow on modal podzols. Thickness and stratigraphy of soil horizons are distinctly heterogeneous and often changing over a distance of just several meters (six different soil profiles were recorded in Stand 30 on an area

Table 4. Biomass, vitality and mycorrhizal infection of fine roots

Stand designation	Biomass of fine roots [g 100 ml^{-1}]			Vitality+	Mycorrhizal infection
	Humus	Mineral	Total	[%]	[g mg^{-1}]
14 healthy	0.309±0.011	0.043±0.002	0.352±0.011	100	unidentified
14 injured	0.317±0.010–	0.030±0.001+	0.347±0.011–	82	unidentified
20 healthy	0.190±0.008	0.023±0.001	0.213±0.009	100	9.53±0.68
20 injured	0.154±0.008+	0.012±0.001+	0.166±0.008+	71	9.56±0.54–
19 healthy	0.622±0.010	0.064±0.001	0.686±0.009	100	7.91±0.36
19 injured	0.463±0.007+	0.051±0.002+	0.514±0.008+	86	7.59±0.27–
40 healthy	0.860±0.008	0.112±0.005	0.972±0.019	100	7.63±0.26
40 injured	0.896±0.004+	0.220±0.005+	1.116±0.009+	71	8.35±0.53+
64 healthy	0.514±0.014	0.146±0.004	0.660±0.016	100	7.8±0.31
64 injured	0.633±0.015+	0.025±0.002+	0.658±0.014–	48	8.5±0.22–
60 healthy	0.638±0.006	0.162±0.005	0.800±0.009	100	8.52±0.28
60 injured	0.556±0.007+	0.144±0.008+	0.700±0.008+	77	7.04±0.08+
40 liming	1.035±0.019	0.098±0.004	1.133±0.021	100	8.67±0.39
40 no liming	1.059±0.022–	0.122±0.005+	1.181±0.012+	54	7.83±0.28+
60 liming	0.881±0.008	0.068±0.004	0.949±0.007	100	7.31±0.12
60 no liming	0.855±0.017+	0.154±0.004+	1.059±0.016+	62	8.79±0.31+
100 liming	0.520±0.013	0.110±0.005	0.630±0.017	100	9.50±0.55
100 no liming	0.474±0.009+	0.111±0.004–	0.585±0.012+	68	9.59±0.51–

+100% = vitality of fine roots in unaffected or limed forest stands of 40 × 40 m). In all injured trees, we found out that the reduced rooting depth results from the shallowly situated and for the roots impenetrable Bs horizon. In the healthy trees, the Bs horizon is penetrable for roots (up to 10 cm of its thickness) and the anchoring roots form in it brushes with fine roots. Although the injured trees create anchoring root systems too, the anchors do not reach the Bs horizon but rather remain in the Ep horizon, in which they hardly show any branching at all, and we recorded even some rots occurring on them. The fact that the roots do not grow into the Bs horizon may be contributed to by chemical changes in the Bhs horizon. The impenetrability of horizon Bs is not induced by chemical changes or by a layer of conglomerates developed in its upper part, but rather by its general mechanical impenetrability to roots (the horizon is difficult-to-dig even with a heavy picker). In both the healthy and injured trees, the root systems appear as if "trimmed" and there are usually no differences between the average and maximal rooting depths.

Less injured or healthy are even trees (stands) with high humus horizons. As a rule, the healthy trees (stands) have a thickness of humus horizons up to 2 times higher than the injured trees (stands). The thickness of humus horizons is not a decisive criterion of damage, though. In young trees, the lower rooting depth results also from root system deformations. It further follows from the analyses that the injured trees have a lesser number of low-diameter horizontal roots. The lower number and thickness of horizontal roots are induced by root system deformations at planting. The occurrence of tangle is a rule namely in younger stands; undecomposed containers were found on the root systems in stands 14 and 10 established with the containerized planting stock. The malformations do not affect the length of horizontal roots. By chemical analyses of basic nutrient contents we detected differences between the healthy and injured trees in the horizon H; the changes may be further deepened by drought (particularly critical being the content of magnesium).

Relations following out from the comparison of results of root system analyses and all other complementary surveys are as follows: Injured trees have a weaker root system, which reaches into lower depths. In the injured trees, the biomass of fine roots is not essentially affected in upper soil horizons; however, the total biomass of fine roots is reduced in the injured trees by up to a half. The mycorrhizal infection in the injured trees is not affected but lower vitality of fine roots was detected (lower abundance of fine roots and their lower vitality markedly impair the capacity of injured trees to uptake nutrients and water). All root system parameters are affected also by the method of planting, the essential influence, however, is that of stratigraphy and both chemical and physical characteristics of soil horizons, which distinctly differ between the individual stands or just within a few meters (damages are observed also on self-seeded trees, without the root system deformation). Stands in the concerned region were not heavily affected by air pollution. In spite of the fact that sulphur depositions near Přebuz are still increasing – up to 1.93 g m^{-2} (Hadaš, 2007). Lomský et al. (2007) report that the assimilatory apparatus of Norway spruce in the region contains the lowest amount of sulphur in the entire Krušné hory Mts. Šrámek et al. (2005) recorded in the surroundings of Přebuz a pronounced increase in both diameter and height increment in the Norway spruce since 1990, which they attributed – similarly as Hadaš (2007) – to the increased nitrogen depositions in the area (up to 28 kg ha^{-1} year^{-1}). The increased depositions of nitrogen may be another important predisposition of the damage. Although the stands grow on poor sites, Šrámek et al. (2005) did not find in the surroundings of Přebuz any critical deficit of some element in the nutrition. Remeš et al. (2007) observed hardly any response of Norway spruce stands to fertilization in the region of study. The effect of these reclamation measures is currently not apparent in stands that were treated with fertilizers and lime in the earliest of the 1990s (Šarman, 1992). Compared with our results, the results in question are different, as they point to a possible disturbance of nutrition. However, the variation results from different methodological procedures of research (health condition of surveyed forest stands, applied fertilizers, methods used in the assessment of nutrient contents, date of sampling for analyses).

By analyzing the development of climate and weather in the concerned region in 1961–2004 (data taken over from the ČHMU hydrometeorological station Nová Ves v Horách, altitude 726 m asl), Bagár (2007) observed mean annual temperatures and growing season temperatures increased by 1.2 °C, insolation extended by 180 hours, number of days with average daily temperature of +5 °C, +8 °C and +10 °C increased by 18, 19 and 26, resp., global radiation since 1984 increased by more than 3,000 J cm^{-2} (which is eg global radiation of the whole month of April). In spite of the fact that according to Bagár (2007) the fitted series showed total precipitation amounts in the growing season increased by 34 mm, the total intensity of precipitation decreased by 0.4 mm, Lang coefficient dropped by 8.5 and potential evapotranspiration increased by 93 mm. The author claims that in the last 15 years, the precipitation amount was markedly lower in April and May with the character of precipitation being in general rather torrential and conspicuously fluctuating in the individual years. A pronounced humidity deficit occurred in years 1989, 1990, 1994, 1998 and 2003.

The above analysis suggests that the predisposing factor for injury is the root system size and quality, which are conditioned by careful planting, particularly by stratification and by the chemical and physical parameters of individual soil horizons. The triggering factor is weather extremes, namely the moisture deficit.

This may be an explanation of striking differences in the course and intensity of damage in individual years or reasons why such a distinct decrease of terminal increment occurred in 2004.

A question remains why the damage to the stands appears only in the recent years. On normal sites, the tree develops a root system, that is to a certain extent capable to eliminate stress factors (root system is "oversized"). In the concerned region, the trees have developed root systems, sufficient in providing for basic life functions (with the index of forest stands being low, though), but the quality of which is not enough for the elimination of a newly emerging stressor – drought, which limits the uptake of water and nutrients. Colour changes to the assimilatory apparatus suggest that an important cause of the decline is the lack of nutrients. The response of Norway spruce assimilatory apparatus to the typical water deficit is somewhat different. The reduced acidity of esp upper soil horizons by liming markedly improves the vitality of fine roots, which makes it possible for trees to increase the uptake of nutrients and water. However, regarding the fact that it does not affect the rooting depth, it may to a certain extent enhance the health condition of the stands but it cannot in general prevent their injury (eg at weather extremes).

Conclusions

The paper analyzes emergence and health condition of root system in the Norway spruce affected by yellowing of its assimilatory apparatus in the area managed by the Forest Administration Horní Blatná. The analyses included 238 trees in twelve forest stands (aged 10–64 years, Forest Type Groups 6K, 7M, modal podzol). The effect of liming was monitored in six forest stands aged 42–117 years.

o The comparison of equally high trees growing one very close to another within one stand, healthy and injured, showed that the injured trees have:
- Smaller and less functional root systems than the healthy trees
- Lower number and smaller diameter of skeletal roots (both horizontal and anchoring), which particularly reflects in lower Index p values
- Reduced rooting depth, worse root pattern distribution and a nearly 100% occurrence of the most serious malformation – tangle
- Increased incidence of honey fungus inducing root rots in some older trees
- Biomass of fine roots reduced by up to 70% over the entire profile studied, with no essential variances found in the upper soil horizons
- Vitality of fine roots reduced by up to 50%
- Similar variances between the root systems of healthy and injured trees were observed both in trees established by planting and in trees from natural regeneration.

o The comparison of healthy and injured trees of approximately the same height occurring in the concerned region revealed that:
- Healthy trees until an age of approx 10 years are those, that have developed large superficial root system; healthy trees from about 20 years are those, that have developed a large anchoring root system with anchors reaching into Bs horizon
- In the injured trees, impaired vitality cleared the ground for the honey fungus, which reduces the size and hence the functionality of the root system by affecting individual root system branches (anchors in particular)
- Liming affected neither the biomass of fine roots nor their mycorrhizal infection however, it increased their vitality.

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Vývin a zdravotní stav kořenového systému smrku ztepilého *(Picea abies* (L.) Karst.) postiženého žloutnutím asimilačního aparátu v oblasti Krušných hor

Souhrn

Práce analyzuje příčiny chřadnutí smrkových porostů na LS Horní Blatná (Krušné hory). Cílem šetření bylo srovnat vývin a zdravotní stav kořenového systému stejně vysokých žloutnutím postižených stromů (s defoliací nebo změnou barvy asimilačního aparátu 40–60 %) a zdravých stromů (bez vizuálních symptomů poškození, případně s defoliací nebo změnou barvy asimilačního aparátu do 10 %), rostoucích v jednom porostu.

V porostech do věku dvacet let bylo vždy analyzováno minimálně 12 stromů, ve dvacetiletých a starších porostech minimálně 6 stromů (zdravých i poškozených). Kořenové systémy byly vyzvednuty ručně a jejich vývin byl posuzován ve vazbě na půdní horizonty. U každého stromu byly měřeny a hodnoceny: celková výška nadzemní části, tloušťka kmene v $d_{1,3}$, délka terminálních výhonů v letech 2004, 2005, deformace kořenového systému do strboulu, počet a tloušťka horizontálních kosterních kořenů, počet a tloušťka kotevních kořenů. Z naměřených hodnot byl vypočítán Index ploch (I_p), který udává vztah mezi velikostí kořenového systému a nadzemní části. Dále byla zjišťována hloubka prokořenění, délka horizontálních kosterních kořenů, úhly mezi horizontálními kosterními kořeny, výskyt václavky, hniloby kořene a kmene, biomasa, životnost a mykorhizní infekce jemných kořenů

- o Ze srovnání stejně vysokých a vedle sebe v jednom porostu rostoucích stromů zdravých a poškozených vyplynulo, že poškozené stromy mají:
- − menší a méně funkční kořenový systém než stromy zdravé,
- − menší počet i tloušťku kosterních kořenů (horizontálních i kotevních), což se výrazně projevuje v menších hodnotách Indexu p,
- − menší hloubku prokořenění, horší rozložení kořenové sítě a téměř stoprocentní výskyt nejzávažnější deformace – strboulu,
- − větší výskyt václavky, která vyvolala i hniloby kořenů,
- − až o 70 % nižší biomasu a až o 50 % menší životnost jemných kořenů,
- − stejné rozdíly mezi kořenovými systémy zdravých a poškozených stromů byly zjištěny jak u stromů založených sadbou, tak u stromů z přirozeného zmlazení.
- o Ze srovnání všech přibližně stejně vysokých stromů zdravých a poškozených v celé zájmové oblasti vyplynulo, že:
- − do věku cca 10 let jsou zdravé ty stromy, které vytvořily velký povrchový kořenový systém, od cca 20 let jsou zdravé ty stromy, které vytvořily velký kotevní kořenový systém a kotvy prorůstají do horizontu Bs,
- − snížení vitality vyvolalo u poškozených stromů nástup václavky, která napadáním jednotlivých větví kořenového systému (obzvláště kotev) snižuje velikost a tím i funkčnost kořenového systému.

Soil properties under different vegetation types in the Arboretum Mlyňany

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Abstract

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The influence of oak trees, and introduced Himalayan pine and Japanese cedar on soil chemical and microbial characteristics was observed in the Arboretum Mlyňany. The original growth on the studied area was an oak-hornbeam forest, therefore the soil under the rest of oak forest was taken as a control. The obtained results showed that changed growth of tree species strongly affected soil microbial and chemical properties. Highly significant ($P < 0.001$) differences in A horizons between the studied stands were found for soil reaction, sorption characteristics, nutrient content (N, P, K), soil organic matter (SOM), and soil microbial biomass. Significantly ($P < 0.001$) the strongest acidity, the highest total organic carbon content (C_T), microbial biomass carbon (C_{mic}) and its proportion of C_T were found in A horizon of the soil under oaks. Higher microbial colonisation of oak soil was probably due to composition of susceptible organic matter and to biodegradation rather than by its amount. We suppose that lower humus quality under deciduous oaks was due to carbonate-less soil forming substrate and the longer period of influence the oak trees (more than 116 years) on soil compared to coniferous pine and cedar trees (45 years).

Key words

pH, carbon, microbial biomass, oak, Himalayan pine, Japanese cedar

Introduction

The Arboretum Mlyňany was established in year 1892 by Dr. Ambrózy-Migazzy and his gardener J. Mišák. It contains many domesticated and acclimatized exotic trees. In the Arboretum resides the Dendrobiological Institute SAS which takes care about, studies and saves endangered woody species (Tábor et al., 1992). Biodiversity conservation and sustainable utilization (mainly protection in situ, protection ex situ and utilization biodiversity components) are the goals of the EU Biodiversity strategy (Macák, 2006). An important national goal is to strengthen the national capacity for ex situ protection – mainly to increase the present net of ex situ institutions, to develop technologies, collections and databases (Sabo et al., 2005).

Soils represent the basic supporting system for terrestrial ecosystems because of their role in providing nutrients, water, oxygen, heat and mechanical support to vegetation. Soil properties considerably influence plant growth and species composition. On the other side, plant cover strongly affects soil forming process and soil chemical, physical and biological characteristics.

Tree species can affect soil properties by several ways. Differences in the physical and chemical characteristics of soils under various species can be caused by different chemical composition of litter and its quantity (Jurčová et al., 2002; Konôpková et al., 2000; Smolander et al., 2005; Tobiašová, 2001), nutrient status, uptake and root activity, rate of elements mobilization (Moszynska, 2001), interception of atmospheric deposition, composition of ground vegetation (Smolander et al., 2005), canopy interactions and leaching as well as alterations of the microclimate and soil's biological community (Priha et al., 1999). Microbial biomass plays the main role in the degradation of soil organic matter, thus microbes exert feed-back-effects on vegetation via mineralisation followed by release of mineral nutrients (Zechmeister-Boltenstern et al., 2000).

The objective of this study was to assess the effect of original oak and introduced tree species (Himalayan pine and Japanese cedar) on selected soil chemical and microbial properties in the Nature Reserve Arboretum Mlyňany.

Material and methods

The Nature Reserve Arboretum Mlyňany is located in south-western part of the Slovak Republic (E 18°21', N 48°19', altitude 165–217 m above sea level). The average annual temperature is 9.4 °C and sum of precipitation is 558 mm (Hrubík, 2000). The Arboretum is situated on Neocene clay, sand and rubble sand, covered with loess, mostly without carbonates (Steinhübel, 1957).

Arboretum consists of an original old Ambrozy's park and new collections, divided according to geographic zones to: East-Asia, North America and Korea trees area, and exposition of Slovak endangered taxons ex situ (Bero et al., 1992).

To assess the soil environment of the site, three soil pits were trenched:

- Soil pit No. 1 under oak wood *(Quercus Cerris,* L.) on Western gentle slope
- Soil pit No. 2 under Himalayan pine wood (*Pinus wallichiana,* Jacson) on Western gentle slope
- Soil pit No. 3 under Japanese cedar wood (*Cryptomeria japonica,* D. Don.) on North-Western gentle slope.

Analyzed chemical parameters: soil reaction – potentiometrically in H_2O, 1M KCl and 0.1M $CaCl_2$; exchangeable base ions (Ca^{2+}, Mg^{2+}, K^+, Na^+) and hydrolytical acidity by Kappen's method; exchangeable Al by method of Sokolov (Hanes, 1999); carbonates – volumetrically, phosphorus (P) and potassium (K) were analysed by method Melich III (Melich, 1984), then P colorimetrically on Spectrophotometer Jenway model 6400 and K on atomic absorption spectrophotometer AVANTA; total soil organic carbon (C_T) – by Tyurin method (Orlov et al., 1981); humus fractionation – by Kononova-Belchikova method (1961) – isolated humus substances (HS) and humic acids (HA); spectral analyses of humic acids – 6400 Spectrophotometer (Jen Way); susceptibility of organic carbon to oxidation by 0.005M $KMnO_4$ solution in acidic medium of 0.0025M H_2SO_4 – (C_L) (Loginow et al., 1993); total nitrogen content – N_T – by Kjeldahl (Bradstreet, 1965). Distribution of C_T, N_T, P, K contents and pH values were analyzed for each 0.1 m layers down to the depth of 0.8 m. Microbial biomass carbon (C_{mic}) was analyzed after the samples were stored for 8 weeks at 4 °C. Fumigation-extraction method (Vance et al., 1987) was used for C_{mic} determination.

Each analysis was done in 3 repeats and in this paper we report the average values. Analysis of variance ANOVA – LSD-procedure was used for statistical evaluation.

Results

The most considerable differences in the soil characteristics under different species were found near the soil surface (0.0–0.1 m), although differences in the lower layer of the A horizon, or other horizons were also large.

Soil reaction values in water were significantly ($P < 0.001$) (Table 5) the most acidic in A horizon and also in the whole soil profile under oak trees compared to coniferous pine and cedar trees. Soil acidity decreased with depth, where the influence of acids from decomposed litter was less intensive (Table 1).

Extremely high values of hydrolytic acidity (H) were found in umbric-A, and argic-Bt horizon under oak trees (H = 157.9 and 133.0 mmol kg^{-1}). High total acidity was in agreement with very high exchangeable Al content in the mentioned horizons.

Sum of base ions (S) and base saturation (BS) were the highest in soil profile under pine trees (Table 1). Differences in the mentioned parameters between the studied soils were highly significant ($P < 0.001$) (Table 5) mainly in A horizons, where the influence of vegetation was the most intensive. Lower parts of profiles, mainly B/C and C horizons were saturated with base ions, which may have been ensued from soil forming substrate (carbonate loess) or from transported base ions to deeper parts of profile by percolating water (Table 1). Whereas the soil profile under oaks did not contain carbonates, in B and C horizons under pine and cedar trees carbonates were identified.

The distribution of N, P, K across the profile is presented in Tables (2–3). Well-supplied with nitrogen, potassium and phosphorus were A horizons under each of the studied trees.

Compared to the other woods, significantly ($P < 0.001$) the highest pool of total nitrogen and available potassium was found in A horizon under cedar trees (Table 3). Significant differences were also found in distribution of macronutrients within the profiles. Nitrogen content gradually decreased with depth in each profile, but phosphorus and potassium only under pine and cedar trees.

Table 1. Soil sorption, pH values and carbonates in soil under oak, pine and cedar trees

Locality	Horizon	Depth [m]	H [mmol kg^{-1}]	S	CEC	Exchang. Al	BS [%]	pH H_2O	pH KCl	pH $CaCl_2$	Carbonates [%]
Oak	Au	0.00–0.15	157.9	50.0	207.9	44.4	24.1	4.62	4.17	4.58	0
	Bt	0.15–0.50	133.0	65.0	198.0	53.9	32.8	4.58	4.12	4.41	0
	Btg	0.50–0.80	44.2	201.0	245.2	2.6	81.8	5.38	4.55	5.02	0
	Btg/C	1.00–1.10	28.3	388.9	417.3	0	93.2	5.70	4.87	5.33	0
Pine	Au	0.00–0.25	29.8	239.0	268.8	0	88.9	6.31	5.18	5.80	0
	A/Bt	0.25–0.35	31.5	262.0	293.5	0	89.4	6.86	5.42	6.61	0
	Bt	0.35–0.60	5.9	286.0	291.9	0	98.0	8.26	7.08	6.35	6.4
	Bt/C	0.60–1.00	5.1	ND	ND	0	ND	8.41	7.34	7.49	9.9
	C	>1.0	4.4	ND	ND	0	ND	8.41	7.44	7.70	11.8
Cedar	Au	0.0–0.2	66.5	169.0	235.5	8.6	71.8	5.21	3.93	4.56	0
	Btg	0.2–0.8	51.6	241.0	294.6	7.0	82.3	5.12	3.68	4.47	0
	Btg/C	>1.0	6.1	267.0	273.1	0	97.8	8.02	6.88	7.27	4.4

H – hydrolytic acidity; CEC – cation exchange capacity; BS – base saturation; ND – no determination; S – sum of bases (Na+, K+, Ca^{2+}, Mg^{2+}); exchang. Al – exchangeable aluminium

Table 2. The content and fractions of organic carbon, and the content of nitrogen, phosphorus and potassium in soil under oak, pine and cedar trees

Locality	Horizon	C_T [g kg^{-1}]	N_T [g kg^{-1}]	P [mg kg^{-1}]	K [mg kg^{-1}]	$C_T : N_T$	C_{mic} [g kg^{-1}]	C_L [g kg^{-1}]	C_{mic} [% of C_T]	C_L [% of C_T]	C_{NL} [% of C_T]
Oak	Au	22.63	1.56	52	183	14.5	0.906	2.397	4.00	10.60	89.4
	Bt	10.31	0.90	10	157	11.3	0.313	0.807	3.04	7.83	92.2
	Btg	5.60	0.68	20	151	8.8	0.248	0.378	4.43	6.75	93.2
	Btg/C	3.96	0.39	58	205	10.1	ND	0.309	ND	7.80	92.2
Pine	Au	11.54	1.14	14	185	10.1	0.073	2.512	0.63	21.77	78.2
	A/Bt	6.62	0.75	10	163	8.8	0.051	0.936	0.77	14.14	85.9
	Bt	3.86	0.71	10	133	5.4	0.106	0.398	2.75	10.32	89.7
	Bt/C	2.40	0.29	12	128	8.2	0.031	0.174	1.30	7.25	92.8
	C	3.15	0.25	14	95	12.7	ND	0.214	ND	6.79	93.2
Cedar	Au	12.15	1.74	14	225	7.0	0.044	1.891	0.36	15.56	84.4
	Btg	2.96	0.74	16	180	4.0	0.032	0.353	1.08	11.93	88.1
	Btg/C	1.85	0.60	12	138	3.1	ND	0.040	ND	2.16	97.8

C_T – total soil organic carbon; N_T – total nitrogen content; P – phosphorus content; K – potassium content; $C_T : N_T$ – ratio $C_T : N_T$; Cmic – microbial biomass carbon; C_L – organic carbon oxidisable by 0.005 mol dm^{-3} $KMnO_4$; C_{NL} – org. carbon susceptible to oxidation by 0.005 mol dm^{-3} $KMnO_4$

Total soil organic matter (SOM) is a key attribute of soil quality since it has far-reaching effects on soil physical, chemical and biological properties. The main indicator of the amount of organic matter is the organic carbon content. Significantly ($P < 0.001$) (Table 5) the highest organic carbon content (C_T) was found in A horizon of oak soil ($C_T = 22.63$ g kg^{-1}). In pine soil it was 11.54 g kg^{-1}, and in cedar soil ($C_T = 12.15$ g kg^{-1}) (Table 2).

The pool of organic matter susceptible to microbial oxidation (determined as labile organic carbon oxidisable by $KMnO_4$ solution – C_L) was similar in profiles under oak and pine trees (mainly in A and Bt horizons). Significantly ($P < 0.001$) (Table 5) the lowest pool of labile carbon was found in A horizon and whole profile under cedar trees (Table 2). On the contrary, comparing the percentage of labile carbon from C_T, the results are different: significantly ($P < 0.001$) the highest C_L of C_T was found in A horizon under pine and the lowest under oak trees (Table 2).

Generally, the C:N ratio controls the rate of SOM decay. Significantly ($P < 0.001$) the highest C:N ratio was found in soil profile under oaks (Table 2). Surprisingly, a very low C:N ratio (7.00) was found in A horizon under cedar trees.

Table 3. The content of carbon, nitrogen, potassium and phosphorus in soil under oak, pine and cedar trees measured in 0.1 m layers

Depth [m]	C_T [g kg^{-1}]			N_T [g kg^{-1}]			K [mg kg^{-1}]			P [mg kg^{-1}]		
	Oak	Pine	Cedar	Oak	Pine	Cedar	Oak	Pine	Ccdar	Oak	Pine	Cedar
0.0–0.1	30.6	26.4	24.3	2.01	1.66	2.36	193	188	315	60	14	14
0.1–0.2	14.2	10.6	10.67	1.11	1.28	1.46	145	150	190	12	10	12
0.2–0.3	10.5	9.06	7.89	0.94	1.05	1.15	143	155	180	10	12	16
0.3–0.4	8.3	4.91	3.50	0.77	0.50	0.67	145	155	195	10	10	12
0.4–0.5	8.2	4.04	2.70	0.78	0.99	0.72	170	125	183	8	10	12
0.5–0.6	5.7	3.40	2.67	0.55	0.49	0.71	188	118	155	12	10	12
0.6–0.7	6.2	3.29	1.75	0.57	0.41	0.56	205	125	158	20	10	14
0.7–0.8	4.9	2.32	2.53	0.93	0.31	0.76	208	113	140	25	10	14
>1.0	3.9	3.15	1.85	0.39	0.25	0.60	205	95	138	58	14	12

C_T – total soil organic carbon; N_T – total nitrogen content; K – potassium content; P – phosphorus content

Table 4. Humus quality in soil profiles under oak, pine and cedar trees

Locality	Horizon	Depth [m]	C_T [g kg^{-1}]	C_{HS} [g kg^{-1}]	C_{HA} [g kg^{-1}]	C_{FA} [g kg^{-1}]	HA : FA	C_{HA} [% of C_T]	$Q_{HA}^{4/6}$ [% of C_T]
Oak	Au	0.00–0.15	22.63	8.97	2.44	6.35	0.38	10.8	4.58
	Bt	0.15–0.50	10.31	4.36	1.42	2.94	0.48	13.8	4.12
	Btg	0.50–0.80	5.60	2.38	1.28	1.10	1.16	22.9	3.91
	Btg/C	1.00–1.10	3.96	1.67	0.80	0.87	0.92	20.2	4.67
Pine	Au	0.0–0.25	11.54	5.28	1.99	3.29	0.61	17.2	5.13
	A/Bt	0.25–0.35	6.62	2.94	1.17	1.77	0.66	17.7	4.82
	Bt	0.35–0.6	3.86	1.88	0.91	0.97	0.94	23.6	5.50
	Bt/C	0.60–1.00	2.40	1.63	0.84	0.79	1.06	35.0	5.33
	C	>1.0	3.15	1.84	0.93	0.91	1.02	29.5	5.00
Cedar	Au	0.0–0.24	12.15	5.85	2.40	3.45	0.61	18.2	7.92
	Btg	0.24–0.8	2.96	1.82	0.91	0.91	1.00	30.7	3.00
	Btg/C	>1.0	1.85	0.91	0.77	0.14	5.50	61.6	ND

C_T – total soil organic carbon; C_{HS} – carbon of humus substances; C_{HA} – carbon of humic acids; C_{FA} – carbon of fulvic acids; HA : FA humic acids to fulvic acids ratio; $Q_{HA}^{4/6}$ – absorbance ratio of humic acids

Microbial biomass carbon content (C_{mic}) was significantly higher in A horizon and also in the whole soil profile under oaks compared to the coniferous stands (Table 2).

Significantly (P < 0.001) (Table 5) the highest amount of C_{mic} was found in A horizon of oak soil (C_{mic} = 0.906 g kg^{-1}), even though the proportion of C_L (as a potentially susceptible organic matter to microbial utilization) of total organic carbon content was the lowest at this site (Table 2). Extremely low C_{mic} contents across the whole soil profile, including the litter layer (results not presented in this paper) were found in coniferous stands (under pine trees = 0.073 g kg^{-1}, and under cedar trees 0.044 g kg^{-1}).

Microbial biomass carbon, as the percentage of the total soil organic carbon (C_{mic}/C_T) in humus layer was significantly (P < 0.001) higher under deciduous trees (4.00%) than coniferous (0.63% under pine, and 0.36% under cedar) (Table 2).

The quality of humus evaluated by HA : FA ratio increased with depth in each profile studied (Table 4). Increased humus quality in deeper parts of profiles was in accordance with increased percentage of non-labile organic carbon (C_{NL}) (Table 2).

Significantly (P < 0.001) (Table 5) the lowest humus quality was found in A and Bt horizons under oaks (HA : FA ratio was only 0.38–0.48). Surprisingly, humus quality under coniferous pine and cedar trees was higher in both profiles (Table 4).

Also degree of humification calculated ($C_{HK} = C_{HK}/C_T$*100 in %) under oak trees indicated significantly (P < 0.001) (Table 5) smaller proportions of SOM transformed to extracted humic acids compared to pine and cedar stands.

Discussion

On the base of their morphological, physical and chemical properties, we classified soil types under pine trees as Haplic Luvisols and under oak and cedar trees as Stagni-Haplic Luvisols (MSCS, 2000).

Table 5. Statistical evaluation: Analysis of variance in A horizons, LSD procedure

Parameter	Oak	Pine	Cedar	Significance
H – Hydrolytic acidity [mmol kg^{-1}]	157.9 c	29.8 a	66.5 b	***
S – Sum of bases [mmol kg^{-1}]	50 a	239.0 c	169.0 b	***
CEC – Cation exchange capacity [mmol kg^{-1}]	207.9 a	268.8 c	235.5 b	***
BS – Base saturation [%]	24.1 a	88.9 c	71.8 b	***
pH H_2O	4.62 a	6.31 c	5.21 b	***
pH KCl	4.17 b	5.18 c	3.93 a	**
pH KCl	4.17 a	5.18 b	3.93 a	***
pH $CaCl_2$	4.58 a	5.80 b	4.56 a	***
C_T – Total organic carbon [g kg^{-1}]	22.63 c	11.54 a	12.15 b	***
C_L – Labile organic carbon [g kg^{-1}]	2.397 b	2.512 c	1.891 a	***
N_T – Total nitrogen [g kg^{-1}]	1.56 b	1.14 a	1.74 c	***
C_{mic} – Microbial biomass carbon	0.906 c	0.073 b	0.044 a	***
C_T/N_T ratio	14.5 c	10.1 b	7.0 a	***
P – Phosphorus [mg kg^{-1}]	52 b	14 a	14 a	***
K – Potassium [mg kg^{-1}]	183 a	185 a	225 b	***
C_{mic} – of C_T [%]	4.00 c	0.63 b	0.36 a	***
C_L – of C_T [%]	10.60 a	21.77 c	15.56 b	***
Non-labile org. carbon – C_{NL} of C_T [%]	89.4 c	78.2 a	84.4 b	***
C_{HS} – Carbon of humus substances [g kg^{-1}]	8.97 c	5.28 a	5.85 b	***
C_{HA} – Carbon of humic acids [g kg^{-1}]	2.44 b	1.99 a	2.40 b	***
C_{FA} – Carbon of fulvic acids [g kg^{-1}]	6.35 c	3.29 a	3.45 b	***
C_{HA} : C_{FA} – Humic to fulvic acids	0.38 a	0.61 b	0.61 b	***
$Q_{HA}^{4/6}$– Absorbance ratio of HA	4.58 a	5.13 b	7.92 c	***
Degree of humification	10.8 a	17.2 b	18.2 c	**
Degree of humification	10.8 a	17.2 b	18.2 b	***

Different letters in one row means values of parameter are significantly different: ** P < 0.01, *** P < 0.001

Our results showed lower pH values under deciduous oak trees compared to coniferous pine and cedar trees. Such results are not in agreement with general knowledge according to which conifer litter is more acidic than deciduous leaf litter and acidification of the soil is more pronounced in the first case. The leachate of this evergreen foliage is usually by 2 units lower in pH value than the leachate moving through deciduous litter, liberating organic acids that may participate in weathering processes (Jahren, 2005). Many authors confirmed strong soil acidity in pine and cedar forests (Farley et al., 2004; Hirano et al., 2000 cit. Kato et al., 1995; Kromka et al., 2003, Yamashita et al., 2004).

We suppose, that significantly ($P < 0.001$) stronger soil acidity under deciduous oaks was due to longer period of their influence on soil (older than 116 years) compared to younger pine and cedar trees (around 45-year-old). Hagen-Thorn et al. (2004) stated that studies in younger plantations, not more than 30-year-old, in temperate regions usually showed an influence on the forest floor only. They observed more distinct differences in soil chemistry in 40- to 50-year-old plantations of different species in upper 0.0–0.1 m, than in lower 0.2–0.3 m soil layer.

Other factor intensively influencing soil acidity is soil-forming substrate. In our study, the substrate under oaks was loess without carbonates, but under pine trees it was carbonate loess. Carbonates were also in Btg/C horizons under cedar trees. Presented carbonates have a high buffering capacity, therefore the soil reaction was neutral or alkaline.

Very low values of soil reaction in solutions KCl and $CaCl_2$ were found in Au and Btg horizons under cedar trees. We suppose that it was due to pseudo-gleyic process. Oak and cedar soil was classified as Stagni-Haplic Luvisol, which usually contains impermeable or slightly permeable layer, therefore soil layer above it is seasonally wet. During wet periods, ion exchange reactions involve iron and manganese in a sequence of reduction-oxidation cycles displacing ions in the reduced phase. Acidic ions as iron, aluminium and manganese are in mobile ionic forms, thus they can contribute to increase in acidity (Hanes et al., 1997).

Since no fertiliser was used in the Arboretum, we suppose that higher concentration of N, P, K macronutrients in humus horizon was due to the decomposed litter. Zimermann et al. (2002) examining a chestnut forest found that an amount of approximately 35% of available soil nutrients are returned each year in litterfall and he stated that the differences in amounts of the returned organic matter and nutrients in the litter could be explained by the site conditions (geology, chemistry, microbiology), the former cultivation, and the biochemical cycles and physiological function of the nutrients.

Special distribution of potassium (K) and phosphorus (P) contents was found in soil under oaks where the second maximum in the mentioned macronutrients content started at a depth of 0.5 m. We suppose that it was due to eluviation process associated with potassium ions leaching from the upper parts of profile, transporting them by percolating water to the lower parts, and binding by soil colloids. The process of leaching was probably supported by fulvic acids, which highly predominated in humus composition (HA : FA = 0.38 in A horizon). In spite of the fact that phosphorus is generally considered as a less mobile macronutrient, it had also its second maximum at 0.5 m from the surface.

Hagen-Thorn et al., (2004) stated that different species may have different even contradictory effects on various components of the P cycle and pools in different soil layers. Higher concentrations of the Fe and Al in the soil solution due to lower pH levels probably lead to higher amount of P precipitated with Al and Fe, and the resulting salts are insoluble.

The labile and total pools of organic carbon were found the highest in oak soil, however, the percentage of labile sub-pool from the total carbon was the lowest just in the soil under oaks. This finding suggests that organic matter in oak soil was more resistant against biodegradation compared to the pine and cedar soil.

Total organic carbon consists of C with varying turnover rates dependent on the relative C unstability of each component. Soil with larger amounts of high-quality C or high-labile C will release higher amounts of CO_2 – since the soil microbial populations can utilize more such C substrates (Mungai et al., 2006). Labile organic matter pools can be considered as fine indicators of soil quality influencing soil functions in specific ways and much more sensitive to changes in soil management practice (Haynes, 2005). The C oxidisable with $KMnO_4$, ie the "labile" carbon mostly comprises soil carbohydrates and some unidentified aromatic compounds, fulvic acids and microbial biomass carbon. Non-oxidisable carbon (C_{NL}) is related to soil humin and stable polysaccharides (Conteh et al., 1999).

In each of the investigated soil profiles $C_T : N_T$ ratio decreased with depth, probably as a result of nitrogen leached to the lower parts of soil profiles, or due to higher content of carbon and less decomposed organic matter in A horizons (Table 2). Studies of many authors confirmed decreasing tendency in C : N ratio with increasing depth of soil profile (Beyer et al., 1993; Hagen-Thorn et al., 2004; Zimmermann et al., 2002). Baytes (1996) concluded that as soil forming process hardly occurred in the soils studied, progressive humification could be expected as decreasing C : N ratio and found with depth in mineral horizons suggesting an increasing degree of SOM decomposition.

Higher $C_T : N_T$ ratio in oak soil suggests that SOM under oak trees had lower quality and therefore it was more resistant to biodegradation compared with the studied conifers (Table 2).

Our findings of higher microbial biomass carbon content (C_{mic}) in deciduous oak soil compared to coniferous stands are in accordance with the results of previous studies dealing with different types of forest ecosystems (Bauhus et al., 1998; Priha et al., 2001; Smolander et al., 2002), although in most of these cases, the deciduous stands were represented by birch. However, according to study of Hackl et al. (2000) it may be suggested that the content of C_{mic} can differ even under the same tree species growing on different soil types.

We suppose that higher abundance of microbes under oaks was due to structure of C_L rather than by its amount itself. However, according to Smolander et al. (2002) soil microbial biomass and activities appeared to be correlated with the total concentration of dissolved organic carbon rather than with its characteristics.

At the all experimental sites C_{mic} tended to decrease with depth. In this case, however, relatively high microbial colonization of soil in Bt or Btg horizon under oaks was determined. The reason of such a phenomenon could be the abundance of organic compounds available for microbial decomposition leached from upper to lower soil horizons by the lessivage process.

Similarly to our findings, the tendency of wider C_{mic}/C_T ratio in soil under deciduous compared with coniferous was reported by Bauhus et al. (1998) or Smolander et al. (2002) who reported higher values for C_{mic}/C_T ratio under deciduous (birch = 2.5%) compared to those under coniferous (pine 1.7%). In the most cases, the C_{mic}/C_T widened with depth, indicating a more intensive decline in organic matter with declining depth than it is the case of microbial biomass. According to Šimek et al. (2002), the C_{mic}/C_T ratio is higher in less fertile soils with low total organic carbon content.

Generally, the conifer soil might have a thick, undecomposed upper horizon with relatively low levels of organic matter below, the grassland might have well-decomposed and well-distributed organic matter throughout the soil profile, and the deciduous system would exhibit properties intermediate to the conifer and grassland profiles (Jahren, 2005).

Sifnificantly lower HA : FA ratio in deciduous soil compared to coniferous suggests, that under deciduous oaks the aggressive fulvic acids dominated in humus composition (Table 4). Lower humus quality under deciduous was confirmed by higher value of colour quotient and lower degree of humification. Similarly to our results, Lesná et al. (2003) also found higher HA : FA ratio under coniferous Norway spruce compared to European beech. But in contrary, degrees of humification were higher under beech, and colour quotient $Q_{4/6}$ showed HA of the beech stand to be more condensed and therefore higher quality than of spruce stand.

In a similar way, Howard et al. (1998) showed higher humus quality in A-horizons under oaks (on limestone average HA : FA = 0.81 and on slates = 1.02). On the contrary, low humus quality in A horizon was found by Bayer et al. (1993) in oak forest on boulder marl substrate with carbonates in deeper subsoil HA : FA = 0.44–0.6.

We suppose that lower humus quality under deciduous oaks resulted from carbonate-less soil forming substrate and also longer presence of oak trees (more than 116 years) influencing the soil compared to coniferous pine and cedar trees (around 45 years). Therefore, the influence of the studied coniferous has not been fully proved.

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Vlastnosti pôdy pod rôznymi druhmi drevín v Arboréte

Súhrn

V práci sme sledovali vplyv porastov dubov (*Quercus Cerris,* L.), borovice himalájskej (*Pinus wallichiana,* Jacson) a kryprомérie japonskej (*Cryptomeria japonica,* D. Don.) na vybrané chemické a mikrobiálne vlastnosti pôd v arboréte Mlyňany. Pôvodným porastom bol dubovo hrabový les, preto sme zachovaný dubový porast vybrali za kontrolný variant. Získané výsledky ukázali, že zmena drevinových druhov výrazne ovplyvnila chemické a mikrobiálne vlastnosti pôdy. Vysoko preukazné ($P < 0{,}001$) rozdiely najmä v A horizontoch medzi sledovanými porastmi boli zistené v hodnotách pH, sorpčných vlastnostiach, obsahu živín (N, P, K), kvalite a kvantite pôdnej organickej hmoty (POH) i mikrobiálnej biomase. Preukazne ($P < 0{,}001$) najvyšší obsah celkového organického uhlíka (C_T) a najsilnejšia acidita boli v A horizonte pod dubmi. Najnižšie zastúpenie mikrobiálne ľahko rozložiteľnej organickej hmoty (C_L) z C_T a najvyšší pomer C : N svedčí o tom, že POH v A horizonte pod dubmi bola značne rezistentná voči biodegradácii. Uhlík mikrobiálnej biomasy (C_{mic}) ako i jeho podiel z C_T boli preukazne ($P < 0{,}001$) najvyššie v pôde pod dubmi, a to predovšetkým v A horizonte. Vysoká kolonizácia tejto pôdy mikróbmi bola pravdepodobne spôsobená skôr zložením C_L než jeho množstvom. Preukazne ($P < 0{,}001$) najnižšia kvalita humusu (HA : FA = 0,38 v A horizonte) potvrdila, že najmä pod dubmi bolo vysoké zastúpenie fulvokyselín. Predpokladáme, že nízka kvalita humusu pod dubmi bola v dôsledku nekarbonátového pôdotvorného substrátu a dlhej doby vplyvu porastu dubov (viac ako 116 rokov) na pôdu v porovnaní so sledovanými ihličnanmi – borovicou himalájskou a kryptomériou japonskou (okolo 45 rokov).

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Soil properties and vegetation on saline-sodic soil in the Nature Reserve Mostová

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Abstract

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The objective of this study was soil-oriented and phytosociological characterization of the saline area in the Nature Reserve (NR) Mostová located in the north-western part of the Danube lowland, Slovakia. A soil pit was trenched into the salt pan covered by a degraded community of *Camphorosmetum annuae*. The community occupying the most salinized plots was fairly frequent in the past, today, however, it is very rare in Slovakia. Soil morphology, physical and chemical parameters were analysed for the whole soil profile containing salt pan, and the chemical properties also for humus horizon (SAe) under the saline growth. We have found that the studied soil was compacted and it had unfavourable aggregate composition of SAe horizon. Aggregate disintegration could be due to prevailing Na^+, which moreover caused a strongly alkaline reaction. Capillary raise of water was documented by dynamic of carbonates, percentage of water-soluble salts and colloids, the amount of which increased in topsoil. The results showed 3 times higher content of NaCl, 1.7 times higher electrical conductivity, 1.5 times higher sodium adsorption ratio, 1.3 times higher exchangeable sodium percentage (ESP) and by 0.6 higher pH values in the SAe horizon containing salt pan compared with SAe horizon under the saline growth. The humus content and quality was low. Based on pH values (ranging 10.57–9.91), ESP (58.7–43.0%) and electrical conductivity of solution (7,000–4,200 $\mu S\ cm^{-1}$) we classified the studied soils as Sodic Solonchacks. The obtained results can contribute to better knowledge on ecology of saline soils in Slovakia and the Danube lowland.

Key words

phytosociological characterization, salt pan, pH, ESP, conductivity, humus

Introduction

Alkaline and salt-affected soils are found on more than half of the Earth's arable lands. They dominate most arid and semiarid regions of the world. Most alkaline and saline soils, however, are not used for agriculture. Their native vegetation provides a variety of wild plants, which, along with their native animals, contri-bute greatly to biological diversity (Brady and Weil, 1999).

Generally, halophyte biotopes belong to the most endangered biotopes in the whole Europe, therefore the

European legislative has ranked them to the important biotopes of prime category (Sádovský et al., 2004).

Some of the most unfavourable properties of salt-affected soils include high salt content, poor structure, limited microbial activity, low percolation rates, low fertility and other characteristics, which restrict plant growth and possibilities for human settlement (Tóth et al., 1991).

In Slovakia, the saline soils are located mainly in lowlands of south and east Slovakia and their acreage was around 30,000 ha in year 1958. Extensive melioration of agricultural soils and regulations of watercourses done in years 1970–1980 prevented continuing salinization process and the acreage of saline soils distinctly decreased (Remiš et al., 1981). Nowadays, the acreage of saline soil is only 4,890 ha of agricultural soil (Bielek, 2004).

Quantifying the interrelationship between soil and vegetation in solonetzic grassland is useful for making an inventory of natural resources; and the occurrence of plants can give quantitative information on the soil properties. The vegetation indicates sharp differences in the status of soil in terms of degradation and in the chemistry of the groundwater (Tóth et al., 1994).

Since soil properties considerably influence plant growth and species composition, and correspondingly, plant cover strongly affects soil forming process and soil chemical, physical and biological characteristics, the aim of the work reported here was soil and phytocenological characterization of the saline area in the Nature Reserve (NR) Mostová.

Material and methods

The NR Mostová is located in the north-western part of the Danube lowland (48°09' N; 17°41' E), altitude 116–118 m. The climate is continental, with an average annual temperature of 10.2 °C and annual precipitation of 539 mm (Špánik et al., 2002). Flat relief was formed by alluvial action of Dudváh and Čierna Voda rivers. The parent material consists of clay, carbonate clay, sandstones, rubble sand or gravel, and it is covered with carbonate sediments of the Danube river: loamy sand, loam, sand and gravel. Groundwater level is deeper than 1.5 m, but capillary rise of water in texturally finer soil reaches topsoil (Linkeš, 1963). On chosen locations of Mostová, the third and fourth degree of landscape protection has been legally recognised. The area is proposed to be protected in frame of the Special Areas of Conservation because its inland saline soils and salty grasslands are important biotopes, and because protection of the species of European importance: *Rhodeus sericeus amarus* and *Lutra lutra* (Anonymous) is necessary.

The phytosociological relevé was carried out according to the Zürich-Montpellier approach using the adapted Braun-Blanquet's scale (Barkman et al., 1964). The nomenclature of flowering plants follows Marhold and Hindák (1998) and the names of syntaxa are according to Molnár and Borhidi (2003).

A soil pit was trenched in the salt pan of saline meadow. The front of soil pit extended into the part of soil containing salt pan on the top and the pit edges into the saline growth. Soil morphology, physical and chemical parameters were analysed for the whole profile of soil containing salt pan. To compare the chemical properties of saline soil containing salt pan with the soil under vegetation, it was collected also a soil sample from humus horizon under the saline growth (in 0.3 m distance from the salt pan).

The soil samples were analysed for the following properties: soil reaction – potentiometrically in H_2O and 1 mol dm^{-3} KCl; exchangeable base cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) (Sotáková et al., 1988), carbonates – volumetrically (Čurlík et al., 2003), water soluble salts content by gravimetric method (Hanes et al., 1995), electrical conductivity – Conductometer S ATC 3120A (Hanes et al., 1995), chlorides in water solution (Hanes et al., 1995), total soil organic carbon (C_T) – by Tyurin method (Orlov et al., 1981), humus fractionation – by Kononova-Belchikova method (1961); spectral analyses of humus substances (HS) and humic acids (HA) – 6400 Spectrophotometer (Jen Way).

Basic physical and hydrophysical parameters (Hanes et al., 1995) were determined to the depth of 0.8 m. Soil texture was determined by pipette method (Hanes et al., 1995).

Each analyse was done in 3 repeats, and in this paper we report the average values.

Results and discussion

The well-preserved mosaic of saline vegetation was developed in the studied locality by the end of the last century. All area of these saline meadows was grazed – which insured conservation of the vegetation cover (Svobodová and Řehořek, 1992). Later, the site was abandoned and negative processes of secondary succession started (biomass accumulation, draining, ploughing etc.). A moment ago, the sub-saline vegetation of *Festucion pseudovinae* predominated and a few small plots of salt pans still survived. Our soil pit was trenched in the salt pan plot occupied by a markedly degraded association of *Camphorosmetum annuae*. The vanishing community merged into vegetation of the alliance *Puccinellion limosae*. This stage is documented by the phytosociological relevé:

Mostová Nature Reserve, sampled area 4 m^2, elevation 2°, exposition: west; E_1: 20%, E_0: 0%, 12. 5. 2005.

Puccinelia distans 2a, *Artemisia santonicum* subsp. *patens* 1, *Camphorosma annua* 1, *Cerastium* *dubium* 1, *Atriplex tatarica* +, *Cynodon dactylon* +, *Tripolium pannonicum* +.

Soil physical properties are listed in Table 1. Since soil forming substrate of the studied locality are alluvial sediments of the Dudváh river, the values of particle density (ρ_s) changed irregularly across the profile. Higher values of particle density in upper parts of the profile were probably caused by mineral composition of the soil forming substrate. Since the critical values of bulk density (ρ_d) and porosity (P) – reported by Zaujec et al. (2002) were exceeded over the whole soil profile, we can conclude that the studied soil was compacted.

The porosity or total pore space, however, does not give any indication of pore size distribution. The optimal pore distribution is: 1/3 macropores – for aeration and 2/3 meso and micropores – for water retention and accumulation (Bedrna et al., 1989). Our results showed that the percentage of meso and micropores exceeded 2/3 of the total porosity (Table 1). The soil moisture (θ) was either sufficient or excessive, and over the whole profile, sufficient amount of utilizable water (W_V) was found.

The low percentage of waterproof aggregates (63.2%) manifested an unfavourable aggregate composition of SAe horizon (Table 2). The main reason for soil structure disintegration was probably the high amount of monovalent cations – mainly Na^+, the percentage of which from the sum of base cations in SAe horizon was even 73.3% (Table 5).

Remiš et al. (1981) stated that adsorption of Na^+ on soil colloids cause the susceptibility of colloids to swelling in wet conditions. It results to disintegration of structure aggregates. During wet state, the saline sodic soils are sticky and gleic, poor aerated and cold, in profile prevail reductive processes decreasing and limiting the activity of soil organisms. In extreme cases Na^+ ions have toxic influence on plant roots. High amount of Na^+ limits water absorption and its transport in plants. Tóth et al. (1991) reported that the Carpatian Basin has hydrologically closed characteristics rather than arid or semiarid conditions. The source of sodium salts is mainly in subsurface water and the dominant forms of salt accumulation are Na_2CO_3 and $NaHCO_3$.

Soil reaction was strongly alkaline over the whole profile studied (Table 4). Such extreme values of pH are very unfavourable for vegetation. The highest va-lue of soil reaction was determined in topsoil where it was found also the highest amount of monovalent base cations – mainly Na^+ and K^+ (Table 5). Hanes (2001) stated that alkaline soil reaction occurs in soils saturated with Na^+ after leaching of water soluble salts. This leads to alkaline hydrolyse and then to Na_2CO_3 formation.

Table 1. Physical and hydrophysical properties of Sodic Solonchack profile

Depth	ρ_s	ρ_d	P	Θ	V_{AM}	Pk	Ps	Pn	W_V	Θv
[m]	[t m^{-3}]		[% vol.]							
0.0–0.1	2.84	1.72	39.4	24.0	15.5	29.7	2.3	7.5	13.7	10.3
0.1–0.2	2.75	1.76	36.5	29.5	6.5	31.4	1.8	3.3	20.9	8.7
0.2–0.3	2.88	1.70	41.0	29.2	11.8	31.7	1.4	7.9	21.8	7.5
0.3–0.4	2.77	1.63	41.1	32.5	9.2	34.9	1.0	5.3	27.7	4.3
0.4–0.5	2.71	1.61	40.6	32.3	8.3	34.1	1.9	4.6	25.5	6.8
0.5–0.6	2.66	1.63	38.7	31.3	7.5	34.0	1.6	3.1	25.1	6.2
0.6–0.7	2.77	1.68	39.4	30.6	4.4	33.5	1.7	4.8	27.6	2.9
0.7–0.8	2.76	1.68	39.1	27.6	11.5	30.4	1.8	6.9	22.1	5.5

ρ_s – particle density; ρ_d – bulk density dray; P – porosity; Θ – water content; V_{AM} – soil aeration; Pk – capillary pores; Ps – semi-capillary pores; Pn – non-capillary pores; Θv – wilting point; Wv – utilizable water

Table 2. Aggregate composition of SAe horizon containing salt pan

Percentage of fractions after dry sieve [%]						
>7.0 mm	7.0–5.0 mm	5.0–3.0 mm	3.0–1.0 mm	1.0–0.5 mm	0.5–0.25 mm	<0.25 mm
4.02	9.74	24.76	31.24	15.08	6.36	8.80
Percentage of waterproof aggregates [%]						
>5.0 mm	5.0–3.0 mm	3.0–2.0 mm	2.0–1.0 mm	1.0–0.5 mm	0.5–0.25 mm	<0.25 mm
22.04	6.36	7.56	9.28	9.60	8.40	36.76

Compared to the SAe horizon containing salt pan, the pH values under vegetation were lower by 0.6. We suppose that higher contents of soil organic matter in SAe horizon under saline vegetation could contribute to decrease in the pH values (Table 4, 6). It is in accordance with Tóth et al. (1994) who refer that the vegetation on solonetzic grassland was the densest at the most acid spots.

Capillary raise of water was documented by dynamics of carbonates, percentage of water soluble salts, colloids and particles with diameter 0.01–0.001 mm, the amount of which increased in the upper parts of soil profile (Table 3, 4).

Our results showed a three times higher content of NaCl in the SAe horizon containing salt pan compared to the SAe horizon under the saline growth (Table 4). The electrical conductivity of soil leach confirmed less favourable conditions for plants growth in soil containing salt pan, since the conductivity of leachate from the SAe horizon was 1.7 times higher compared to SAe horizon under the saline growth.

ESP (exchangeable sodium percentage) and SAR (sodium adsorption ratio) values were calculated from the determined content of base ions. Our results suggest that Na^+ was the dominant cation over the whole soil profile (Table 5). The highest content and percentage of Na^+ from the sum of base cations and therefore also the highest values of ESP and SAR were found in the (Bnt)SCc horizon. The 1.5 times higher values of SAR and 1.3 times higher values of ESP in the SAe horizon with the salt pan points out a worse cation composition compared with the SAe horizon under the saline growth.

On the base of ESP values being higher than 20% over the whole profile, the values of soil reaction higher than 8.5 and values of solution electrical conductivity higher than 4,000 μS cm^{-1}, we can classify the studied soil as a Sodic Solonchack (WRB, 1994).

Generally, the content and quality of humus in saline and sodic soils is low (Hanes, 1997, Remiš et al., 1981). Our results showed that the content of humus in the whole profile under the salt pan was very low, but in the SAe horizon under the saline growth it was evidently higher – because the plant residues and root exudates permanently enriched this horizon with organic compounds (Table 6). The quality of humus in the SAe horizons was very low (amount of humic acids – HA was lower than fulvic acids – FA), but in the deeper parts of profile it increased. Higher humus quality in deeper parts of profile was confirmed by the degree of humification (percentage HA of humus) which also increased in depth.

Since salt-affected soils and mainly saline vegetation, microbial and animal species are very rare in Slovakia, additional research and mapping is necessary.

Table 3. Textural composition of Sodic Solonchack

Horizon	Depth	Texture	Textural fractions [%]					
			>0.25	0.25–0.05	0.05–0.01	0.01–0.001	<0.001	<0.01
	[m]		mm	mm	mm	mm	mm	mm
SAe	0.0–0.08	ssh	0.1	5.4	10.0	69.5	15.1	84.5
(Bnt)SCc	0.08–0.5	ssh	0.2	19.8	51.2	19.4	9.5	28.9
(Bnt)SCc	0.5–1.1	sp	0.3	49.7	35.9	10.8	3.3	14.1
CGo(S)c	1.1–2.0	sp	5.7	50.7	31.5	9.8	2.3	12.1

ssh – silt loam; sp – sandy loam

Table 4. Values of pH, content of chlorides, NaCl, conductivity and mineralization of water

Horizon	Depth	pH H_2O	pH KCl	Cl^-	NaCl	CO_3^{2-} HCO_3^-	Water soluble salts	Electrical conductivity
	[m]			[%]				[μS cm^{-1}]
Profile with salt pan on the top								
SAe	0.00–0.08	10.57	9.58	0.11	0.17	30	0.45	7,000
(Bnt)SCc	0.08–0.50	10.46	9.47	0.15	0.25	26	0.46	7,350
(Bnt)SCc	0.50–1.10	10.21	8.99	0.11	0.18	11	0.29	4,750
CGo(S)c	1.10–2.00	10.02	8.88	0.08	0.13	14	0.26	3,850
SAe horizon under halophyte plants								
SAe	0.0–0.1	9.91	9.02	0.03	0.06	28	0.33	4,200

Table 5. Base cations, and their percentage of sum of base cations, SAR and ESP

Horizon	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Σ	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SAR	ESP
	[mmol (p^+) kg^{-1}]					[% of sum of cations]				[%]	
SAe	30.0	12.5	233.2	42.5	318.2	9.4	3.9	73.3	13.4	50.6	55.4
(Bnt)SCc	35.0	–	226.3	16.1	277.4	12.6	0.0	81.6	5.8	54.1	57.3
(Bnt)SCc	32.5	7.5	253.7	7.3	301.0	10.8	2.5	84.3	2.4	56.7	58.7
CGo(S)c	55.0	63.6	150.8	5.1	274.7	20.0	23.2	54.9	1.9	19.6	30.8
SAe horizon under halophyte plants											
SAe	35.0	16.3	164.6	51.3	267.1	13.1	6.1	61.6	19.2	32.5	43.0

Σ – sum of base cations ($Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$); SAR – sodium adsorption ratio; ESP – exchangeable sodium percentage

Table 6. Organic carbon content and humus

Horizon	Humus	C_T	C_{HS}	C_{HA}	C_{FA}	C_{HA}/C_{FA}	C_{HA}	$Q_{HS}^{4/6}$	$Q_{HA}^{4/6}$
	[g kg^{-1}]						[% of C_T]		
Profile with salt pan on the top									
SAe	4.22	2.45	1.00	0.42	0.58	0.73	17.1	4.82	3.45
(Bnt)SCc	2.95	1.71	0.98	0.53	0.45	1.02	31.0	3.25	2.21
(Bnt)SCc	2.74	1.59	1.04	0.49	0.56	0.88	30.8	3.60	2.13
CGo(S)c	2.29	1.33	1.00	0.71	0.29	2.46	53.4	3.20	2.00
SAe horizon under halophyte plants									
SAe	30.55	17.72	2.89	1.22	1.66	0.74	6.9	7.50	4.00

Humus = C_T * 1.724; C_T – total content of organic carbon; C_{HS} – carbon of humus substances; C_{HA} – carbon of humic acids; C_{FA} – carbon of fulvic acids; C_{HA}/C_{FA} – humic acids to fulvic acids ratio; $Q_{HS}^{4/6}$ – absorbance ratio of humus substances; $Q_{HA}^{4/6}$ – absorbance ratio of humic acids

Conclusions

- The vegetation of salt pans was degraded in the study site.
- The studied soil was compacted over the whole profile.
- The main reason of soil structure disintegration (only 63.2% of waterproof aggregates) was probably in high amount of monovalent cations – mainly Na^+.
- Since Na^+ was the dominant cation in the whole profile, soil reaction was strongly alkaline.
- Capillary raise of water was documented by dynamics of carbonates, percentage of water soluble salts, colloids and particles with diameter 0.01–0.001 mm, the amount of which increased in the upper parts of soil profile.
- Our results showed 3 times higher content of NaCl, 1.7 times higher electrical conductivity, 1.5 times higher values of SAR, 1.3 times higher values of ESP and by 0.6 higher pH values in the SAe horizon containing salt pan compared to the SAe horizon under saline growth. The content and quality of humus in the studied soils was low. Humus content decreased and humus quality gradually increased with depth.
- On the base of pH, ESP values and electrical conductivity of soil solution, we classified the studied soil as a Sodic Solonchack.
- The results obtained in this study enable us to know better the present state and ecology of saline soils in Slovakia and in the Danube lowland.

Acknowledgement

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Vlastnosti a vegetácia alkalických slaniskových pôd Prírodnej rezervácie Mostová

Súhrn

Robili sme pôdnu a fytocenologickú charakteristiku salinických pôd v Prírodnej rezervácii Mostová, ktorá sa nachádza v severozápadnej časti Podunajskej nížiny na Slovensku (48°09' SŠ; 17°41' VD), nadmorská výška 116–118 m. Bola vykopaná pôdna sonda na zanikajúcom slanom oku s rudealizovaným porastom *Camphorosmetum annuae*. V minulosti bolo toto spoločenstvo viazané na najviac zasolené pôdy pomerne časté, no v súčasnosti je veľmi vzácne. Morfologické, fyzikálne a chemické vlastnosti boli stanovené pre celý pôdny profil pod slaným okom. Na porovnanie chemických vlastností pôd so slaným okom na povrchu s pôdou pokrytou slanomilnou vegetáciou sme odobrali aj vzorku pôdy z humusového horizontu (SAe) pod porastom slaniska (asi v 0,3 m vzdialenosti od

slaného oka). Zistili sme, že skúmaná pôda bola utlačená, a v celom profile bol dostatok využiteľnej vody. Nízke percento vodoodolných agregátov (63,2 %) bolo dôkazom nepriaznivého agregátového zloženia SAe horizontu. Toto mohlo byť spôsobené prevahou Na^{+} katiónov v sorpčnom komplexe, ktoré pravdepodobne zapríčinili aj silne alkalickú reakciu v celom pôdnom profile. Kapilárny zdvih vody bol dokázaný na základe dynamiky karbonátov, obsahu solí, koloidov a častíc s priemerom 0,01–0,001 mm, ktorých obsah bol najvyšší vo vrchnej časti pôdneho profilu. Zistili sme, že SAe horizont slaného oka mal trojnásobne vyšší obsah NaCl, 1,7-násobne vyššiu vodivosť pôdneho roztoku, 1,5-násobne vyššiu hodnotu pomeru adsorpcie sodíka (SAR), 1,3-násobne vyššiu hodnotu percenta výmenného sodíka (ESP), a o 0,6 vyššiu hodnotu pH v porovnaní so SAe horizontom pod slaniskovou vegetáciou. Obsah a kvalita humusu skúmanej pôdy boli nízke. Keďže hodnoty pH v profile boli v rozmedzí 10,57–9,91, hodnoty ESP boli v rozmedzí 58,7–43,0 % a elektrická vodivosť roztoku bola v rozmedzí 7 000–4 200 $\mu S\ cm^{-1}$, klasifikovali sme skúmanú pôdu ako slanisko slancové. Získané výsledky môžu prispieť k lepšiemu poznaniu ekológie slaniskových pôd Slovenska a Podunajskej nížiny.

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Relationships between parameters of aboveground parts and parameters of root plates in spruce trees growing in poorly drained sites

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Abstract
Štofko, P., Kodrík, M. 2008. Relationships between parameters of aboveground parts and parameters of root plates in spruce trees growing in poorly drained sites. *Folia oecol.*, 35: 67–73.

In the locality Hnile Blatá (the High Tatras Mts) we measured the aboveground parts (tree height, stem diameter, length and width of crowns) of windthrown spruces (*Picea abies* (L.) Karst.). The width and thickness of root plates were measured on the belowground parts. The methods of linear regression and correlation analysis were used to evaluate the relationships between the aboveground and the belowground parts. Extreme wide and shallow root plates were found out in spruces growing in poorly drained sites. The higher degree of statistically significant correlation was found out between the individual stem diameters and the root plate parameters. The medium values of multiple correlation coefficients were found out among the root plate parameters and the tree height, width and length of crown. The low degree of correlation was found out between the crown proportion index and the belowground parameters of root plates. The partial correlation coefficients point out that the correlation only exists between the average width of root plate (AWrp) and the individual aboveground parameters. No correlation was found out between the thickness of root plates (Trp) and the individual aboveground parameters.

Key words
root plate, Norway spruce, poorly drained sites

Introduction

The morphology and size of tree root system is predetermined by the genetic properties of particular tree species, as manifested through interspecies differences. However, the environment (especially soil conditions) can influence root system features considerably (Coutts, 1987).

Research on tree root system is less frequent than studies on the aboveground parts because of a variety of reasons. Root systems are not directly visible to the unaided eye and they are of less economic importance than the aboveground biomass. Tree root system research is also very laborious and its methods are not as well developed as procedures for the aboveground biomass inventory. The belowground biomass inventory methods have been comprehensively described by Köstler et al. (1968), Kolesnikov (1972), Böhm (1979) and recently by Smit et al. (2000).

In Slovakia, extensive research of tree root system has been done by Kodrík (2002) who investigated the root systems of main forest trees in term of static stability. Konôpka (2001, 2002) compared root systems

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of trees with respect to soil drainage. Kodrík (2005) analysed the root biomass of forest woody plants in view of productive ecology.

The root system is usually in contact with several parts of the soil profile which differ in water, air and nutrient content, texture, bulk density, organic material and pH, whereas the soil profile is generally considered to consist of layers, and the conditions in each layer are treated separately (Smit et al., 2000). The depth of penetration of a root system is mainly influenced by soil properties and humidity. However, rooting is influenced by many other factors little investigated by now because it is not easy to follow a root system growth.

In undisturbed development, spruce forms typical shallow root system. The rootedness gets shallower with worsening soil aeration (Köstler et al., 1968). Maximum depth of root penetration can also be reduced by a high groundwater table.

The purpose of this paper is to evaluate the relationships between parameters of the main aboveground parts and root plates in spruces growing in poorly drained sites.

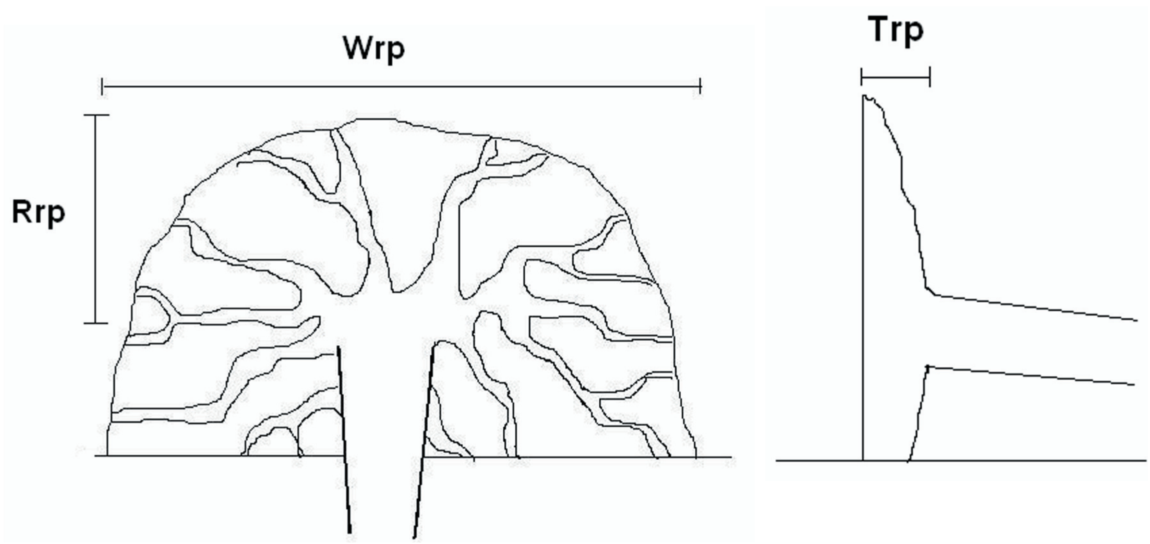
Material and methods

The aboveground parts and root systems were measured on Norway spruces (*Picea abies* (L.) Karst.) uprooted by wind in the locality Hnilé Blatá (the High Tatras Mts). This site is uneven-aged, with the over storey 90 years old, south aspect, 5–10% slope, altitude is about 950 m asl. Management set of forest type is waterlogged fir-spruce. The site consists of the forest types: peaty fir-spruce (50%) that belongs to the vegetation unit Abieto-Piceetum, birch-alder on a fluvio-glacial substrate (40%) that belongs to the vegetation unit Betuleto-Alnetum and bilberry-spruce with fir (10%) that belongs to the vegetation unit Piceetum abietinum higher stage (Križová, 1995). Spruce is the dominant woody plant at the site, but the birch and alder are also quite abundant. The soil is rather waterlogged, with low incidence of peats.

Altogether, 77 windthrown spruce trees were measured. For the aboveground biomass the following parameters were measured: stem diameter on the ground level ($D_{0.0}$), stem diameter 20 cm from the ground level ($D_{0.2}$), diameter at breast height (DBH), ie 130 cm from the ground level, tree height (H), crown length (L) and crown width (Wc). Crown proportion index Cpi = L/H × 100 values were calculated.

For the belowground biomass, the following parameters were measured: horizontal width of root plate (Wrp), vertical radius of root plate (Rrp), and thickness of root plate (Trp) (See Figs 1 and 2). The average width of root plate (AWrp) was calculated according to the formula: AWrp = (Wrp + 2Rrp)/2. The mean values of all aboveground and belowground biomass characteristics were calculated.

The relationships between the root plate thickness as well as average root plate width and the aboveground biomass parameters were analyzed statistically, using multiple linear correlation and regression analysis. Values of multiple correlation coefficients were calculated. These multiple correlation coefficients indicated the degree of correlation among the individual aboveground parameters (dependent variable) and the average width (AWrp) and thickness (Trp) of root plates (independent variables). The values of partial correlation coefficients were calculated too. These partial correlation coefficients indicated the degree



Figs 1 and 2. Measurement of the root plate parameters: root plate width (Wrp), distance from the stem centre to the windward edge – vertical radius of root plate (Rrp) and root plate thickness (Trp) across the plate of correlation between the individual aboveground parameters and the average width of root plates (AWrp) and between the individual aboveground parameters and the thickness of root plates (Trp). The parameters of regression equation were calculated. These parameters were calculated in order to estimate the individual aboveground parameters (dependent variable) on the basis of the root plate parameters (independent variables).

Results

Mean values of the aboveground biomass characteristics of Norway spruce are shown in Table 1. Mean value for DBH was 32 cm, for $D_{0.2}$ it was 41 cm and for $D_{0.0}$ it was 49 cm. Mean value of tree heigth was 22.5 m. Mean value of crown width was 5.04 m. Relatively high mean value (16.4 m) of crown length was found out in this locality. Mean value for crown proportion index was 72%, thus the statical stability of spruces growing in this locality should be rather favourable.

Mean values of the root plate parameters are shown in Table 2. Mean values for belowground biomass are the following: for horizontal width it was 5.04 m, for vertical radius it was 1.56 m and for thickness of root plates it was 30.5 cm. Mean value of calculated average width of root plates was 4.08 m. These data indicate rather wide and shallow root plates of spruces growing in poorly drained sites.

Values of multiple correlation coefficients of linear dependence among the individual aboveground parameters and the average width and the thickness of root plates are shown in the upper part of Table 3. Values of partial correlation coefficients of linear dependence between the individual aboveground parameters and the average width of root plates and between the individual aboveground parameters and the thickness of root plates are shown in the last two lines at the bottom of Table 3. The higher degree of correlation was found out between the individual stem diameters and the average width of root plates. The highest degree of correlation ($r = 0.62$) was found out between the $D_{0.0}$ and the average width of root plates. Medium degree of correlation was found out between the tree heights, width and length of crowns and the average width of root plates. Low degree of correlation was found out between the crown proportion index and the average width of root plates. In this case, the value of correlation coefficient was only 0.22 and it was

Table 1. Mean values of the aboveground parameters of Norway spruce (± standard deviation)

Number of measured trees	Stem diameter			Tree height	Crown		Crown proportion index
	DBH	$D_{0.2}$	$D_{0.0}$	H	Width (Wc)	Length (L)	Cpi = (L/H) × 100
	[cm]	[cm]	[cm]	[m]	[m]	[m]	[%]
77	32.05±7.61	40.91±10.33	49.19±13.27	22.59±2.65	5.04±1.36	16.41±2.92	72.65±9.70

Table 2. Root plate parameters of Norway spruce (arithmetic mean ± standard deviation)

Number of measured trees	Horizontal width of root plate (Wrp)	Vertical radius of root plate (Rrp)	Average width of root plate (AWrp)	Thickness of root plate (Trp)
	[m]	[m]	[m]	[cm]
77	5.04±1.32	1.56±0.70	4.08±1.15	30.51±5.13

Table 3. Values of correlation coefficients of linear dependence among individual aboveground parameters and root plate width (AWrp) and root plate thickness (Trp) in Norway spruce

Statistics	Stem diameter			Tree height	Crown		Crown proportion index
	DBH	$D_{0.2}$	$D_{0.0}$	H	Width (Wc)	Length (L)	Cpi = (L/H) × 100
Multiple R	0.60*	0.60*	0.62*	0.51*	0.51*	0.46*	0.22^{n}
AWrp	0.58*	0.60*	0.61*	0.50*	0.51*	0.46*	0.16^{n}
Trp	0.08^{n}	0.03^{n}	0.03^{n}	0.08^{n}	$–0.07^{n}$	$–0.06^{n}$	$–0.16^{n}$

*statistically significant correlation coefficient, $p < 0.05$, ^{n}statistically insignificant correlation coefficient statistically insignificant. No correlation was found out between the individual aboveground parameters and the thickness of root plates. In these cases, the values of correlation coefficients were close to zero.

The graphical representations of 3-dimensional linear correlation among the individual aboveground parameters and the average width and thickness of root plate are shown in the Figs 3–9. After insertion of linear plane into the graphs it is apparent that the values of individual aboveground parameters increase with increasing values of average width of root plates. The values of thickness of root plates increase only with the increasing values of DBH, $D_{0.2}$, $D_{0.0}$ and tree height. On the linear plane, the values of thickness of root plates are almost straightened with the values of width and length of crowns. The values of crown proportion index increase with decreasing values of thickness of root plates.

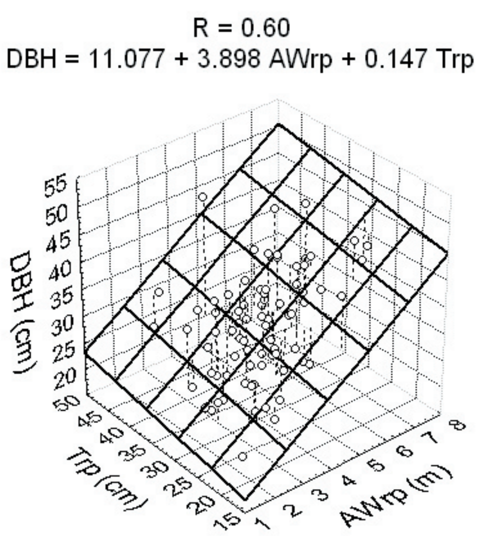


Fig 3. Presentation of 3-D linear correlation among DBH values and calculated average width (AWrp) and thickness (Trp) of root plates

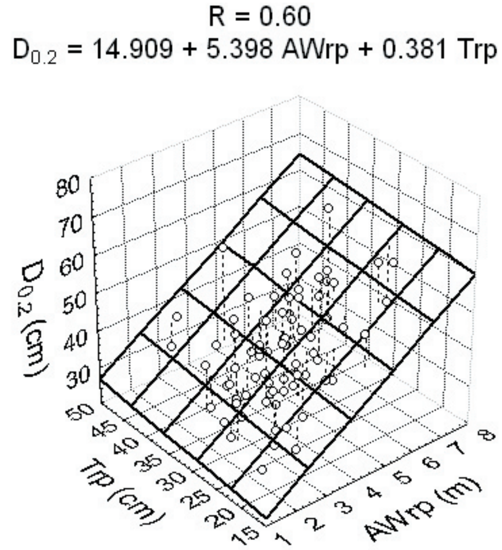


Fig 4. Presentation of 3-D linear correlation among $D_{0,2}$ and calculated average width (AWrp) and thickness (Trp) of root plates

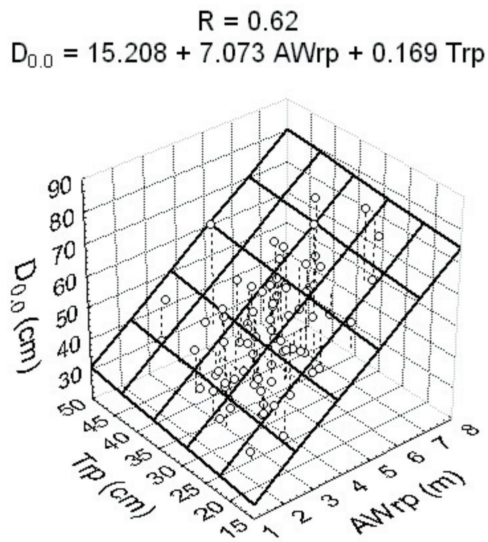


Fig 5. Presentation of 3-D linear correlation among $D_{0.0}$ and calculated average width (AWrp) and thickness (Trp) of root plates

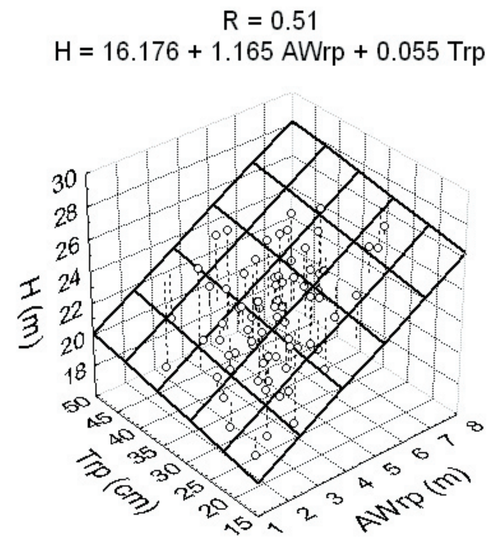


Fig 6. Presentation of 3-D linear correlation among tree height (H) and calculated average width (AWrp) and thickness (Trp) of root plates

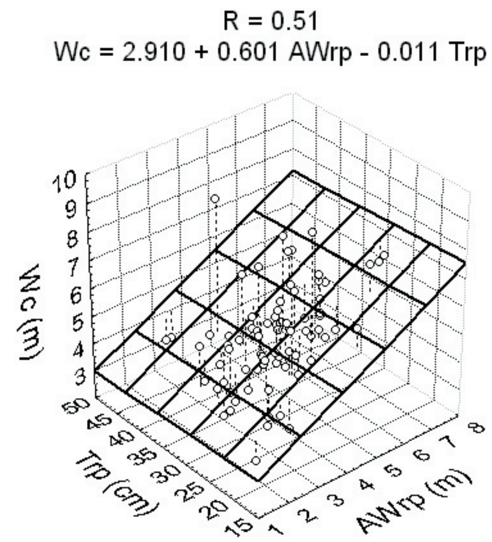


Fig 7. Presentation of 3-D linear correlation among tree crown width (Wc) and calculated average width (AWrp) and thickness (Trp) of root plates

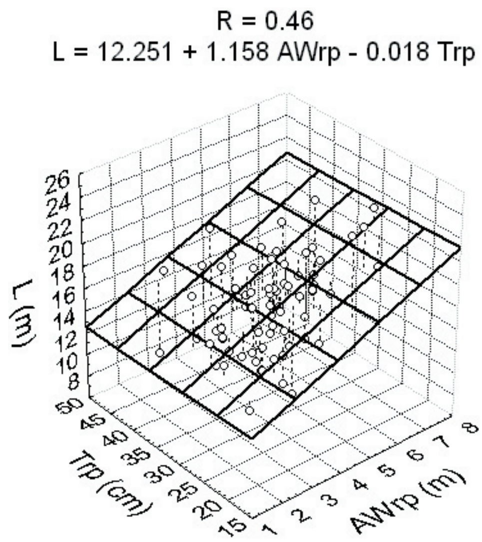


Fig 8. Presentation of 3-D linear correlation among tree crown length (L) and calculated average width (AWrp) and thickness (Trp) of root plates

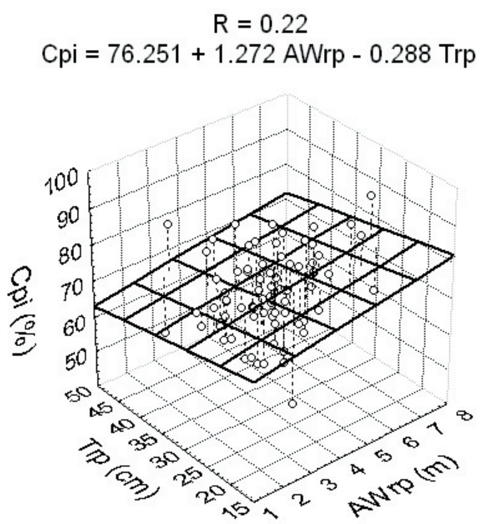


Fig 9. Presentation of 3-D linear correlation among crown proportion index (Cpi) and calculated width (AWrp) and thickness (Trp) of root plates

Discussion

High mean value of crown length may refer to favourable aboveground parameters of static stability of spruce trees growing in this locality. Similarly, Konôpka (2000) found out higher values of crown length of spruce trees growing in poorly drained sites. Cucchi et al. (2003) found out that trees of *Pinus pinaster* growing on wet land have significantly a greater relative crown length than those growing on dry land.

Our results point out the fact that root systems of spruce trees growing in poorly drained sites are extreme wide and shallow. Similarly, Konôpka (2001, 2002) found out wide and shallow root systems of Norway spruces growing in poorly drained sites in the High Tatras Mts. Interestingly, the mean value of crown width (Wc) is the same as the mean value of root plate width (Wrp), which was measured in the same horizontal direction. Kodrík (1983) found out that the root system of Norway spruce exceeded the circumference of crown. This author found out that the width of spruce root system in the locality Hronec was wider by 94 cm than the width of crown. On the other hand, Konôpka (2002) found out lower values (more or less half-values) of root system widths than the values of crown widths of spruce trees growing in well-drained sites. Contrariwise, this author found out that the values of root plate widths were higher than the values of crown widths of spruce trees growing in poorly drained sites. For example, Kodrík and Kodrík (1996) found out that the values of crown widths were higher than the values of root system widths in fir trees growing in well-drained sites. Konôpka (2002) found out that the root systems of spruce trees growing in poorly drained sites were broader by one-third units than those in well-drained sites.

The mean value of root plate thickness was only 30 cm. This type of shallow root system, even though broad, is unstable and reduces the positive effect of high value of crown length on spruce stability. Konôpka (2002) found out that the root systems were two times shallower in poorly drained sites than in well-drained sites. Similar results were obtained by Rottmann (1986), who claimed that permanently waterlogged sites did not allow tree roots to penetrate the deeper horizons due to insufficient oxidation. Štofko (2006) points at an increase in root plate width corresponding to an increase in DBH, but he found out that the average values of root plate depth were in all stem diameter classes almost identical (around 30 cm). Nicoll and Ray (1996) found out that the spread of the root system of *Picea sitchensis* trees and the ratio of root mass to shoot mass (root/shoot ratio) were both negatively related to soil-root plate depth.

Our results point out that the correlation exists only between the individual aboveground parameters and the width of root plates. We found out no correlation between the individual aboveground parameters and the thickness of root plates. Gruber and Lee (2005) found out narrow correlation ($r^2 = 0.96$) between DBH and coarse root dry mass for spruce trees growing in well-drained sites. Similarly, we found out the highest correlation between the stem diameters and the root plate widths. Konôpka (2001) evaluated the root system depth and width of spruce, fir, beech, larch and pine and compared interspecific differences in root system measurements. This author found out higher degree of correlation between the width of root plates and the DBH than between the depth of root plates and the DBH. Konôpka (2002) found out statistically significant correlation between the DBH, $D_{0.2}$, crown width, slenderness ratio and the width and the depth of root plates. Interestingly, this author found out statistically significant correlation between the aboveground parameters and the depth of spruce root plates growing in poorly drained sites. These results do not correspond to our results, because we found out no correlation between the aboveground parameters and the thickness of root plates. This phenomenon may reflect deeper (mean value 45 cm) and narrower (mean value 315 cm) root plates found out by Konôpka (2002). This author found out statistically insignificant correlation between the crown proportion index and the depth of root plates, and it agrees with our results. However, he observed that correlation between the crown proportion index and the width of root plate was statistically significant in the locality Kežmarské Žľaby, but it was statistically insignificant in the locality Rosengard (both localities in poorly drained sites).

For example, Nicoll et al. (2006) found out positive linear correlation between coarse root volume and stem volume for *Picea sitchensis*. Similarly, Di Iorio et al. (2005) analyzed root system architecture in *Quercus pubescens*. They found out that the diameter at breast height was the best predictor of root volume, however lacking correlation with root length and number. Schmid and Kazda (2001) found out no correlation either between root diameter and soil depth for monospecific stand of spruce.

Conclusions

The vertical distribution of roots hangs on soil aeration, compression, and moisture-holding capacity of the particular soil horizons. In general, relatively shallow and little spread root systems are found at fertile and moist sites where trees have sufficient water and nutrients supply in the upper soil layer. Our research also confirmed that spruce trees had considerably wide and shallow roots at the poorly drained sites. Our partial results document that the growth and distribution of roots are influenced by conditions in available underground water. It seems that this factor has mainly impact on the root system's depth.

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Vzťahy medzi parametrami nadzemných častí a parametrami koreňových koláčov na smrekoch rastúcich na podmáčaných stanovištiach

Súhrn

V lokalite Hnilé Blatá (Vysoké Tatry) sme zmerali nadzemné a podzemné časti smrekov vyvrátených vetrom. Z nadzemných častí sa kvantifikovala: hrúbka kmeňa v prsnej výške $d_{1,3}$ (DBH), hrúbka kmeňa vo výške 20 cm od úrovne pôdy ($D_{0,2}$), hrúbka kmeňa na úrovni pôdy ($D_{0,0}$), výška stromu (H), dĺžka (L) a šírka koruny (Wc). Vypočítané boli hodnoty korunovosti podľa vzťahu Cpi = L/H × 100. Z podzemných parametrov sme meraním zistili:

Horizontálnu šírku (Wrp), vertikálny polomer (Rrp) a hrúbku (Trp) koreňových balov podľa obrázkov 1 a 2. Vypočítali sme priemernú šírku koreňových koláčov (AWrp) podľa vzťahu: AWrp = (Wrp + 2Rrp)/2. Vypočítali sme priemerné hodnoty uvedených parametrov (Tabuľka 1 a 2). Na vyhodnotenie vzťahov medzi nadzemnými a podzemnými časťami smrekov sme použili metódy lineárnej regresnej a korelačnej analýzy.

Výsledky práce poukazujú na extrémne široké a plytké koreňové baly smrekov rastúcich na podmáčaných stanovištiach. Vyšší stupeň štatisticky významnej korelácie sme zistili medzi jednotlivými hrúbkami kmeňa a rozmermi koreňových balov. Stredné hodnoty mnohonásobných korelačných koeficientov sme zistili medzi rozmermi koreňových balov a výškou stromu, šírkou a dĺžkou koruny. Nízka a štatisticky nevýznamná korelácia existuje medzi korunovosťou a podzemnými parametrami koreňových koláčov. Pri hodnotení parciálnych korelačných koeficientov sme zistili vyššie a štatisticky významné hodnoty korelačných koeficientov iba medzi šírkou (AWrp) koreňových balov a jednotlivými nadzemnými parametrami. Medzi hrúbkou (Trp) koreňových koláčov a jednotlivými nadzemnými parametrami smrekov neexistuje takmer nijaká závislosť (Tabuľka 3).

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Development of phytocoenoses and of above ground production of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) stands on the PRP series Ivanka pri Nitre

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Abstract

Tokár, F., Kukla, J. 2008. Development of phytocoenoses and of above ground production of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) stands on the PRP series Ivanka pri Nitre. *Folia oecol.*, 35: 74–87.

There was studied the influence of moderate crown thinning on development of phytocoenoses and above ground dendromass production in pure and mixed stands of introduced species *Quercus rubra* L. and *Juglans nigra* L. Owing to succession process during more than 40 years the other 17 autochthonous tree species, 7 of them (41%) shrubs, have been penetrated in studied stands. The phytocoenoses contain 56 herb species including abundant indicators of the wetted edaphic-hydric order of geobiocoens manifesting that the water regime of soils has not been substantially disturbed by hydro-melioration of surrounding land and the Nitra riverbed regulation. Geobiocoenoses in which the series of permanent research plots has been established belong to the nitrophilous order of geobiocoens, group of forest types Ulmeto-Fraxinetum carpineum and forest type 954 Dry elm-ash forest with hornbeam. The highest reserve of above ground dendromass (686.81 m^3 ha^{-1}, 486.50 t ha^{-1}) and highest mean periodic annual increment (20.58 m^3 ha^{-1} $year^{1}$, 14.18 t ha^{-1} $year^{-1}$) were found in the 48-year-old non-tended stand of red oak (80%) and black walnut (20%). The highest growth index of standing volume (414.30%) and the highest percentage of mean periodic annual increment (12.57%) were observed in the tended stand of black walnut (20%) and small-leaved linden (80%), while the highest growth index of dry weight reserve (526.85%) and highest mean periodic annual increment (17.07%) were found in the tended stand of black walnut (80%) and red oak (20%). The highest volume reserve of final-crop trees (299.57 m^3 ha^{-1}) was also found in the non-tended mixed stand of black walnut (80%) and red oak (20%), while the highest weight reserve (230.98 t ha^{-1}) and the highest mean periodic annual increment (11.27 m^3 ha^{-1} $year^{-1}$, 10.68 t ha^{-1} $year^{-1}$) were in the tended stand of red oak (80%) and black walnut (20%).

Key words

red oak, black walnut, crown thinning, soil properties, changes of phytocoenoses, development of dendroproduction

Introduction

Red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) belong to the introduced tree species considerable distributed in Slovakia (Benčať, 1982). Their cultivation is well-founded with regard to high growth and yield ability (Réh J., 1967, 1989, 1995; Tokár 1979, 1987a, 1991a, b, 1996, 1998, 2000), resistance against airborne pollutants and tracheomycoses (Juhásová and Hrubík, 1984), as well as usability in orchard management, forest management and furniture industry (Réh R., 1992a, b, 1994, 1996).

In this work are evaluated geobiocoenological conditions and influence of moderate crown thinning with positive selection and interval of five years on course of successive processes and development of production of pure and mixed red oak and black walnut stands.

Materials and methods

The stands of the studied introduced species were established in years 1954–1956 in territory of the Forest District Nitra (Forest Enterprise Palárikovo). There had been bed out one-year-old plants of red oak and sowed the black walnut seeds (provenance Sereď) in triangular spacing. The territory is situated in the warm climatic region A with a mean annual temperature of 9.7 °C and mean annual precipitation of 580 mm (Petrovič a kol., 1968). The phytocoenoses were described and geobiocoenoses classified according to Zlatník (1976a, b) and Hančinský (1972). The plant taxa were determined and named according to Dostál (1989).

The series of six permanent research plots (PRP), each 50 × 50 m in area, was established in stands 131k (PRP I, II, III, VI), 131h (PRP IV) and 131d (PRP V) of introduced tree species in the year 1978. The trees on each PRP were marked with numbers. Since 1978, the PRP I to V were subjected to moderate crown thinning with positive selection and five-year interval, PRP VI has been left as control. The purpose of thinning is to regulate the development of the red oak – black walnut and black walnut – small-leaved linden mixed stands in such a way as to reach maximum in both wood mass and quality production. The used method is based on thinning of final-crop trees (Tokár, 1991a, b, 1992a, 1996, 1998, 2000), that means trees with appropriate qualitative (tree classes 1 and 2, stem and crown quality degrees 1 and 2) and quantitative parameters (thicker than the mean stand diameter $d_{1,3}$ and higher than mean stand height). The thinning schedule is in Table 1.

The stands on PRP were evaluated each 5 years (1978, 1983, 1988, 1993, 1998 and 2003) following the methods by Tokár (1982a, b, 1983, 1984, 1991a). The amount of above ground dendromass was determined with using the destructive method (Tokár, 1986a, b, 1987a, b, 1991b, 1992b). The necessary number of sample trees for analysis was determined based on stratified selection from the individual tree classes with an allowable error of 10% (Šmelko, 1963). In years 1978 and 1983 was selected 30 sample trees (owing to considerable variability of stem diameter $d_{1,3}$ in the tree classes), in years 1988, 1993, 1998 and 2003 only 15 sample trees. There was determined closeness of correlation between the dry weight dendromass determined at 105 °C and fresh leaf area on one side and the stem diameter $d_{1,3}$, tree height and crown length and width on the other. The closest relations were found to stem diameter $d_{1,3}$ and as most suitable function was second-degree parabola (Tokár, 1998). The dendromass stock was calculated from the smoothed values of dendromass and number of trees in the individual diameter classes. The area of three representative fresh leaf samples (3 × 100 leaves) taken from each tree species of stand was determined using a photo-planimeter EJKELKAMP. The leaf area of trees in diameter classes and stands was ascertained by means of conversion coefficient (kg m^{-2}) calculated from the average fresh leaves weight and area of sample trees.

The influence of thinning on development of standing volume and weight stock as well as on the total stand production (standing volume + thinning + mortality + other losses) was evaluated through growth index, periodic mean annual increment and total mean increment.

Table. 1. Thinning schedule realised on the PRP series Ivanka pri Nitre

PRP	Woody plant		Thinning				Age in		Thinning in	
			Intensity	Type	Method	Interval	1978	2003	1978	2003
	species	[%]					[years]		[chronology]	
I	Quercus rubra L.	20	Moderate	Crown	Positive selection	5-year	24	49	First	Sixth
	Juglans nigra L.	80					23	48		
II	Quercus rubra L.	100					24	49	First	Sixth
III	Quercus rubra L.	80					24	49	First	Sixth
	Juglans nigra L.	20					23	48		
IV	Juglans nigra L.	100					22	47	First	Sixth
V	Tilia cordata Mill.	80					17	42	First	Sixth
	Juglans nigra L.	20					21	46		
VI	Quercus rubra L.	80	Control plot				24	49	Without thinning	
	Juglans nigra L.	20					23	48		

Results

Geological and soil conditions

The series of permanent research plots is situated at an altitude of 150 m, on an alluvial floodplain of the Nitra river. In the lower part of the floodplain are late Tertiary gravel-sands covered in the Holocene by skeleton-less loamy flood sediments containing small amounts of carbonates.

The humus horizons are thick 6–8 cm, and they contain, in general 0.1–0.20%, very rarely even 0.45% of carbonates (PRP V). The content of carbonates in soils increases downwards on plots II, III and VI, while on plots I, IV and V it first moderately decreases up to the values of 0.05–0.10% (inside the layer 50–60 cm), and than it again increases in the lower layers of soil profile. The maximum amounts of carbonates (0.4–1.0%) were found at a depth of 100–110 cm (Bublinec, 2002; Bublinec and Janík, 1992).

The formed brown soils have features of both fluvisols and cambisols, and according to Collective (2000) they can be not unambiguously classified. The fact that their profile is dominated by browning horizons B containing small amounts of carbonates, allow us to classify them as Eutri-Cambic Fluvisols, on PRP V as Calcari-Cambic Fluvisols.

Actual reaction of fluvisols is ranging between 7.0 and 8.2. Neutral reaction was only found in the upper 0–60 cm layer of soils on PRP II and VI and in the 50–60 cm layer of soils on PRP III and V. The limit value of actual reaction 7.2 in the upper 0–5 cm soil layer differentiating the neutral and moderate alkaline soils and at the same time the heminitrophilous edaphic-trophic interorder (B/C) and calciphilous order (D) of geobiocoens (according to Kukla, 1993) was exceeded on PRP I, III, IV and V.

In the past, the soil surface on PRP was flooded episodically, these floods, however, were only short-lasting. The alluvial sediments show namely only very slightly signs of gleying, even at a depth of 100 cm. At present, these soils are not flooded any more or very rarely and for very short periods only. The ground water table is most part of year outside the main rhizosphere of forest stands. Its level depends on the water amount of the Nitra riverbed the flowage of which could be however partially changed owing to hydromelioration of the surrounding land and riverbed regulation. The extent to which these treatments have been reflected in changes of water regimen dynamics of PRP soils is not known, because the fluctuation of the Nitra river water level is not observed systematically.

The values of average moisture content in surface layer of these soils (up to a depth of 25 cm) range, according to Bublinec and Janík (1992) in the growing season from 18–20% without substantial differences between them. The highest soil water storage in the upper 25 cm soil layer was found on PRP V (496 m^3 ha^{-1}), the lowest on PRP I (457 m^3 ha^{-1}). The most favourable conditions for surface humus accumulation were found on control PRP VI (dry weight 15.7 t ha^{-1}), the lowest accumulation is on PRP V (dry weight 9.2 t ha^{-1}) where the dominant woody plant is small-leaved linden.

Phytocoenological and geobiocoenological conditions

Before the planting with the introduced tree species, the soil on PRP was tilled. Owing to succession processes that proceeded during their development have been formed the forest communities presented in Table 2.

After 42–49 years, the underwood in the stands of the introduced tree species was enriched with other 17 species, 7 of them (41%) shrubs, in a natural way. The most species – 15 (88%), have penetrated into the stand of red oak on PRP II and into the stand of black walnut and red oak on PRP I – 12 (71%), the least into the stand of black walnut and small-leaved linden on PRP V – 3 (18%), where the shadowing ability of small-leaved linden was markedly manifested. On PRP III were found 8 (47%) new woody plant species, on PRP IV there were 9 (53%) and on the control PRP VI the number of woody species was 10 (59%).

The black walnut regeneration was best on PRP I, III, IV and VI. Rarely it was found even on the most shadowed PRP V, together with sporadic present autochtonous species as *Acer campestre*, *Fraxinus excelsior*, *Tilia cordata* and *Tilia rubra*. Red oak begins with fructification in advanced age only, and at present, there is no regeneration of this tree species on the PRP series. From the autochthonous tree species, *Fraxinus angustifolia*, *subsp. danubialis* is abundantly present in undergrowth on almost all the studied plots (except PRP V), on the PRP I along with *Acer pseudoplatanus* and *Ulmus minor*, on the PRP II with *Acer pseudoplatanus, Tilia rubra* and *Acer campestre*, and on PRP III with *Acer pseudoplatanus* and *Tilia rubra*. From the shrubs are more abundant the species tolerating only short-term influence of floods, as *Sambucus nigra* (PRP I)*, Swida sanquinea* (PRP I and IV) and *Euonymus europaeus* (PRP III). The abundance of the other shrub species is low.

The herb layer of the PRP stands comprises populations of 56 species, including 13 (23%) grasses and grass-like species. The most herb species were found on plots PRP IV – 36 (64%), the least on plots PRP V and VI – 18 (32%). The total number of species on PRP I was 33 (59%), on PRP II 9 (52%) and on PRP III 26 (46%). The highest proportion of grasses and grass-like species to the other herbs was found on PRP V (80%), substantially lower it was on control PRP VI (29%) and on PRP I (27%), and the lowest values were found on PRP IV (24%), PRP III (23%) and PRP II (21%).

Table 2. Geobiocoenological characteristics of the PRP series Ivanka pri Nitre

Permanent research plot	I	II	III	IV	V	VI
Silvicultural intervention	Moderate crown thinning with positive selection and 5-year interval					Control
Date of releve	10. 8. 2004					
Altitude [m]	150					
Inclination [°]	0					
Forest vegetation tier	2. beech-oak					
Edaphic-hydric order	Wetted					
Edaphic-trophic order	heminitrophilous B/C					
Group of forest types	Ulmi-fraxineta carpini superiora pannonica					
Forest type	954 – Dry elm-ash stand with hornbeam; *Brachypodium sylvaticum*, *Rubus caesius, Convallaria majalis,* (*Dactylis glomerata subsp. polygama*)					
Parent rock	Alluvial sediments					
Soil – Variety	Eutri-				Calcari-	Eutri-
Soil – Subtype	Cambic					
Soil – Type	Fluvisol					
Stocking	$0.8^{0,6}$	0.7–0.9	0.8–0.9	0.6	0.9	$0.9^{0,8}$
Canopy [%]	80^{70}	80	80–90	70	90–100	90

Woody species complex						
Taxon	Cover [%]					
1 *Acer pseudoplatanus*	–	+				
Juglans nigra	60		40	90	60	40
Quercus rubra	20	70	20–30			30
2 *Juglans nigra*				10		
Quercus rubra	20–30	30	30–40			30
Tilia cordata					40	
4 *Acer campestre*		–	+	+		
Acer pseudoplatanus	+–5	–				
Fraxinus angustifolia	+–5	–		5–10		
Juglans nigra	+			5		
Quercus cerris				+		
Quercus rubra	10–20	+	5–10			10–20
Tilia cordata					+	
Ulmus minor	+–5	–		+		
Corylus avellana	+	+				+
Euonymus europaeus	+					
Prunus spinosa				+		
Sambucus nigra	$+–5^{30}$			+		
Staphylea pinnata		–				
Swida sanquinea	+			10–20		
5_{1a} *Acer campestre*	+	+ –5	+	+		+
Acer platanoides	+	+	+			
Acer pseudoplatanus	+	5–10	+–5			+
Cerasus avium						–
Fraxinus angustifolia	+	+–5		+		
Fraxinus excelsior	–	+				+

Table 2. Continued

Permanent research plot	I	II	III	IV	V	VI
Silvicultural intervention	Moderate crown thinning with positive selection and 5-year interval					Control
5_{1a} *Juglans nigra*	$5–10^{30}$	+	20–30	10–20	+	+
Quercus rubra	+	+	+–5			+
Tilia cordata					+	
Tilia rubra	+	+–5	+–5			+
Ulmus minor	+			+		
Corylus avellana	+					
Crataegus monogyna						–
Euonymus europaeus	+	+		+		
Prunus spinosa		+		+		
Sambucus nigra		–	+			
Swida sanquinea	+-5		-	$+\text{-}5^{70}$		
5_{1b} *Acer campestre*	+	+	+		+	+
Acer platanoides			+			
Acer pseudoplatanus		+	+			+
Cerasus avium						–
Fraxinus angustifolia		5–10	+–5		+	$5–10^{30–40}$
Juglans nigra	+–5	+–5	+–5	+–5	+	10–30
Quercus rubra	+–5	20	+			+
Quercus sp.	–			–		–
Tilia rubra	+	–	+		+	+
Ulmus minor		–				
Euonymus europaeus	+	+	+–5	+		+
Prunus spinosa		+				
Swida sanquinea		–		$+^{10}$		
5_2 *Tilia rubra*						+
Herbal complex						
Total cover [%]				80		
Grasses and grassy species [%]				+–5		
Other herb species [%]				75–80		
Taxon	Cover					
Brachypodium sylvaticum	$–2^{–3}$	$+^{+2}$	+	$+^{–3}$	$+^{–2}$	+ ÷1
Bromus benekenii		+1	–		+	
Bromus sterilis				$0÷1^{–3÷–4}$		
Carex acutiformis				$+^{+2}$		
Carex pilosa	$0÷+^{+2}$	0÷+3	0÷+3			$+ ÷1^{±2}$
Carex sylvatica	+	+	+	+	+ ÷1	$+ ÷1^{–2}$
Dactylis glomerata					+1	
Elymus caninus	$+^{+2}$	+		$1÷–2^{+3}$	+	
Melica uniflora					$+^{+2}$	
Milium effusum	+1			$+^{1}$	+ ÷1	
Poa nemoralis			$+^{–3}$	$+^{+2}$		
Vignea divulsa	$+^{+2}$		+			
Vignea muricata	$+^{–2}$				+	+
Ajuga reptans	–		$+^{1}$			
Alium scorodoprassum		–		+1 (dry)		

Table 2. Continued

Permanent research plot	I	II	III	IV	V	VI
Silvicultural intervention	Moderate crown thinning with positive selection and 5-year interval					Control
Alliaria petiolata	1	$+\div1^{-2}$	$+\div1^{+2}$	$+\div1^{-2}$		1^{+2}
Arctium sp.				+		
Campanula trachelium		–				
Chenopodium polyspermum				–		
Circaea lutetiana	–2	1÷–2	$1\div-2^{+2}$	-2^{+3}		+ ÷1
Clematis vitalba	$+^{+3}$					
Convallaria majalis	$+^{+2}$	$1\div-2^{-3}$	$+\div1^{+3}$		+–2	$+^{+2}$
Cucubalus baccifer	+			$+^{+2}$		
Epilobium montanum				–		
Fallopia dumetorum	+	+				
Galeopsis pubescens				–		
Galium aparine	$+\div1^{+2}$	1^{+2}		$\pm2^{+3}$	$+^{1}$	
Geranium robertianum	±2			$1\div-2^{+4}$		$1\div+3^{+4}$
Geum urbanum				–		
Glechoma hederacea	$1\div-2^{-3}$	$+\div1^{+2}$	$1\div-2^{+3}$	$+\div1^{+2}$	+	$-2^{+3\div+4}$
Hedera helix	$1\div-2^{+4}$	$1\div-2^{+3}$	$+^{+3}$		$+^{+4}$	$+^{+4}$
Heracleum sphondylium	–			+		
Humulus lupulus				+		
Impatiens parviflora	+	–	–			
Lactuca seriola				+		
Lamium maculatum	$\pm2^{+3}$	±2	1÷–2	$+2^{+4}$	$1\div-2^{-3}$	$1\div-2^{+3}$
Lapsana communis	–			+		
Lysimachia nummularia		$+^{+2}$	$+^{+2}$			
Melandrium album	–					
Mercurialis perennis	$1\div\pm2^{+4}$	$1\div+2^{+3}$	$1\div\pm2^{+3}$	$+2^{-5}$	$-2^{\pm3}$	$1\div-2^{\pm3}$
Polygonatum latifolium			$+^{\pm3}$			
Polygonatum multiflorum	+	+	+	$+^{-2}$	+	+
Pulmonaria obscura	1^{+2}	1	1	+ ÷1	$1\div-2^{+2}$	$1\div-2^{+2}$
Pulmonaria officinalis	1	+ ÷1	+	1^{-2}		
Rubus caesius	1^{+2}	+ ÷1	1÷–2	$1\div-2^{+2}$		+ ÷1
Rubus idaeus				$+^{1}$		
Rumex sanquineus	+	+		–		
Solanum dulcamara		–				
Solanum nigrum				–		
Stachys sylvatica	$+\div1^{-2}$	$+^{-2}\div1$	$+^{-2}$	1^{+3}		
Stellaria media	$+-^{3\div+4}$					
Torilis japonica		–	+	$+\div1^{+2}$		
Urtica kioviensis	$-2^{-3\div-4}$	$+^{+2}$	$+^{-2}$	$+^{+2}$		$+^{-2}$
Veronica chamaedrys						$+^{+2}$
Viola hirta	+	$+^{+2}$	+	+	+	$+^{-2}$
Viola reichenbachiana		+ ÷1	+ ÷1		$+^{1}$	

The basis of herb layer create abundant to dominant heminitrophilous to nitrophilous species as *Glechoma hederacea, Lamium maculatum, Mercurialis perennis* and, with exception of PRP V, also *Alliaria petiolata* and gradational *species Urtica kioviensis.* Additional species indicating increased amounts of plant accessible soil nitrogen is *Geranium robertianum* – the species abundant to dominant occurring on PRP I, IV and V, *Galium aparine* – abundant on PRP I, II, IV and *Elymus caninus* – sporadic to abundant present on PRP I, II, IV and V.

From mesotrophic species on PRP I, and II is abundant the lignifying liana *Hedera helix* and on PRP II and III *Convallaria majalis*. On the other plots, except of PRP IV, the gradation of these two species was observed. Sporadic to abundant is also the occurrence of mesotrophic to neutrophilous species *Brachypodium sylvaticum*, *Pulmonaria officinalis*, *Pulmonaria obscura* and *Rubus caesius*, as well as mesotrophic species *Circaea lutetiana*. The last two species and the sporadic to abundant occurring species *Elymus caninus, Milium effusum* and *Carex acutiformis* point out, at the same time, the moister soil environment, corresponding, sensu Zlatník et al. (1970) approximately to the 3th forest vegetation tier.

The above-discussed facts show evident that the water regime of PRP series was not substantially disturbed by hydromeliorative treatment of surrounding agricultural land and of the Nitra riverbed regulation, and the studied geobiocoenoses may be still regarded as component of the wetted edaphic-hydric order of geobiocoens. The strong dominance of heminitrophilous to nitrophilous species point out high content of for-plants-accessible nitrogen, presence of the nitrophilous edaphic-trophic order and, according to the more recent classification by Zlatník (1976a, b) also presence of group of types of geobiocoens Ulmi-fraxineta carpini superiora. Following Hančinský (1972), the geobiocoenoses in which the PRP series was established can be classified to the wet set and nitrophilous order of geobiocoens, group of forest types Ulmeto-Fraxinetum carpineum and forest type 954 – Dry elm-ash forest with hornbeam, with combination of the species *Brachypodium sylvaticum, Rubus caesius, Convallaria majalis, (Dactylis glomerata subsp. polygama)*.

Development of volume and weight stock of above ground dendromass of stands

In 2003, the highest volume stock of above ground dendromass (686.81 m^3 ha$^{–1}$) and the highest mean periodical volume increment (20.58 m^3 ha$^{–1}$ year$^{–1}$) of stand, were reached on the control PRP VI. The highest growth index value (414.30%) was obtained in the tended mixed stand of black walnut and small-leaved linden. In this stand type, there was also found the highest increment percent (12.57%), which is by 5.36% higher compared to the control PRP VI (Table 3).

The highest weight stock of above ground dendromass (486.50 t ha^{-1}) and the highest mean periodical weight increment of stand (14.18 t ha$^{–1}$ year$^{–1}$) was also found in the control PRP VI. The highest growth index of the weight stock (526.85%) was reached in the mixed stand of red oak (20%) and black walnut (80%) on PRP I. In this stand was also found the highest increment per-cent (17.07%), in comparison with PRP VI higher by 58.97% (Table 4).

Development of total volume and weight production of above ground dendromass of stands

In 2003, the highest total volume production (791.70 m^3 ha$^{–1}$) and the highest total periodical increment (16.29 m^3 ha$^{–1}$ year$^{–1}$) were found on the control PRP VI (Table 3). The total volume production of the tended stands was lower from 11.08% (PRP III) to 21.67% (PRP I).

The highest total weight production of above ground dendromass (561.59 t ha$^{–1}$) and the highest total mean weight increment (11.54 t ha$^{–1}$ year$^{–1}$) of stand were also reached on the control PRP VI (Table 4). The total weight production of tended stands was lower from 12.22% (PRP III) to 29.29% (PRP V).

Development of abundance and production of final-crop trees

In 2003, the highest number of final-crop trees was found on PRP V (823 pcs ha$^{–1}$, from which 470 pcs ha$^{–1}$ was black walnut), the lowest on PRP I (200 pcs ha$^{–1}$, from which 160 pcs ha$^{–1}$ was black walnut). The highest volume stock of final-crop trees was found on PRP VI (299.57 m^3 ha$^{–1}$), and the highest weight stock was on PRP I (230.98 t ha$^{–1}$). The mean periodical volume increment reached maximum on PRP III (11.27 m^3 ha$^{–1}$ year$^{–1}$) and in comparison with control PRP VI was higher by 15.71% (Table 5). The highest mean periodical weight increment of above ground dendromass (10.68 t ha$^{–1}$ year$^{–1}$) was found on PRP I, being by 39.79 % higher compared to the control.

The mean quality of final-crop tree stems of black walnut (1.14) in 2003 was higher in comparison with red oak (1.34). Owing to thinning the mean quality of red oak stems increased by 0.34 degree, and of black walnut stems by 0.28 degree. The values of leaf area index ranged between 0.30 ha a$^{–1}$ (PRP IV) and 1.35 ha a$^{–1}$ (PRP V).

Discussion

The forest stands composed of red oak and black walnut require an appropriate thinning schedule founded on relevant data on stand structure, development and quality, with the aim to control appropriately the

Table 3. Development of above ground volume production of different stand types on series of PRP Ivanka pri Nitre

Permanent research plot	Woody plant		Age in 1978	Stock in 1978 after thinning	Stock in 2003 before thinning	Growth index of stock	Mean periodical increment (MPI)		Growth index (MPI to PRP VI)	Age of woody species in 2003	Total volume production to Dec. 31, 2003	Total mean increment (TMI)	Growth index (TMI to PRP VI)
	species	[%]	[years]	[m^3 ha^{-1}]		[%]	[m^3 ha^{-1} $year^{-1}$]	[%]	[%]	[years]	[m^3 ha^{-1}]	[m^3 ha^{-1} $year^{-1}$]	[%]
I	*Quercus rubra* L.	20	24	20.14	32.40	160.87	0.49	2.43		49	61.21	1.25	
	Juglans nigra L.	80	23	89.97	401.84	446.64	12.47	13.86		48	552.30	11.51	
	Total	100		110.11	434.24	394.37	12.96	11.77	98.66		613.51	12.76	78.33
II	*Quercus rubra* L.	100	24	154.79	437.84	282.86	11.32	7.31	61.27	49	662.08	13.51	82.93
III	*Quercus rubra* L.	80	24	112.70	304.20	269.92	7.66	6.80		49	460.43	9.40	
	Juglans nigra L.	20	23	38.25	174.67	456.65	5.46	14.27		48	242.35	5.05	
	Total	100		150.95	478.87	317.24	13.12	8.69	72.84		702.78	14.45	88.92
IV	*Juglans nigra* L.	100	22	147.58	430.39	291.63	11.31	7.66	64.21	47	629.62	13.40	82.26
V	*Tilia cordata* Mill.	80	17	26.82	131.76	491.27	4.20	15.65		42	180.16	4.29	
	Juglans nigra L.	20	21	93.96	368.63	392.33	10.99	11.69		46	406.57	8.84	
	Total	100		120.78	500.39	414.30	15.19	12.57	105.36		586.73	13.13	80.60
VI	*Quercus rubra* L.	80	24	120.30	425.96	354.08	12.23	10.16		49	504.65	10.30	
(Control)	*Juglans nigra* L.	20	23	52.12	260.85	500.48	8.35	16.02		48	287.05	5.98	
	Total	100		172.42	686.81	398.33	20.58	11.93	100.00		791.70	16.29	100.00

Table 4. Development of above ground weight production of different stand types on series of PRP Ivanka pri Nitre

Permanent research plot	Woody plant		Age in 1978	Stock in 1978 after thinning	Stock in 2003 before thinning	Growth index of stock	Mean periodical increment (MPI)		Growth index (MPI to PRP VI)	Age of woody species in 2003	Total weight production to Dec. 31, 2003	Total mean increment (TMI)	Growth index (TMI to PRP VI)
	species	[%]	[years]	[t ha^{-1}]		[%]	[t ha^{-1} year^{-1}]	[%]	[%]	[years]	[t ha^{-1}]	[t ha^{-1} year^{-1}]	[%]
	Quercus rubra L.	20	24	15.17	24.39	160.78	0.35	2.31		49	47.56	0.87	
I	*Juglans nigra* L.	80	23	54.52	342.77	628.70	11.53	21.15		48	421.00	8.77	
	Total	100		69.69	367.16	526.85	11.90	17.07	158.97		468.56	9.64	83.53
II	*Quercus rubra* L.	100	24	124.17	263.40	212.13	5.56	4.48	41.76	49	409.59	8.36	72.35
	Quercus rubra L.	80	24	97.95	215.75	220.26	4.71	4.81		49	330.95	6.75	
III	*Juglans nigra* L.	20	23	25.00	125.36	501.44	4.01	16.00		48	162.06	3.38	
	Total	100		122.95	341.11	277.44	8.72	7.09	66.04		493.01	10.13	87.78
IV	*Juglans nigra* L.	100	22	83.47	319.73	383.05	9.45	11.32	105.42	47	416.37	8.86	76.78
	Tilia cordata Mill.	80	17	22.86	55.92	244.62	1.32	5.78		42	85.59	2.04	
V	*Juglans nigra* L.	20	21	67.29	257.86	303.21	7.62	11.32		46	281.37	6.12	
	Total	100		90.15	313.78	348.06	8.94	9.92	92.36		366.96	8.16	70.71
VI	*Quercus rubra* L.	80	24	108.17	292.89	270.77	7.39	6.83		49	355.44	7.25	
(Control)	*Juglans nigra* L.	20	23	23.87	193.61	811.10	6.79	28.44		48	206.15	4.29	
	Total	100		132.04	486.50	368.45	14.18	10.74	100.00		561.59	11.54	100.00

Table 5. Development of above ground production of final-crop trees and index of leaf area in stand types on series of PRP Ivanka pri Nitre

Permanent research plot	Woody plant (stand type)	Number of final-crop trees in 2003	Stock in 1983 (after intervention)		Stock in 2003 (before intervention)		Mean periodical increment (PPP)		Growth index (PPP to TVP VI)		Index of leaf area in 2003
		[ps ha^{-1}]	[m^3 ha^{-1}]	[t ha^{-1}]	[m^3 ha^{-1}]	[t ha^{-1}]	[m^3 ha^{-1}]	[t ha^{-1}]	[%]		[ha ha^{-1}]
	Quercus rubra L.	40	7.43	2.79	27.84	22.23	1.02	0.97			0.16
I	*Juglans nigra* L.	160	18.81	14.62	205.76	208.75	9.35	9.71			0.21
	Total	200	26.24	17.41	233.60	230.98	10.97	10.68	106.47	139.79	0.37
II	*Quercus rubra* L.	328	25.80	16.03	171.84	109.25	7.30	4.66	74.95	60.99	1.04
	Quercus rubra L.	260	24.11	19.99	154.53	107.22	6.52	4.36			0.91
III	*Juglans nigra* L.	120	23.81	18.67	118.87	54.11	4.75	1.77			0.13
	Total	380	47.93	38.66	273.40	161.33	11.27	6.13	115.71	80.23	1.04
IV	*Juglans nigra* L.	255	33.69	27.77	226.69	169.93	9.65	7.11	99.07	93.06	0.30
	Tilia cordata Mill.	353	19.04	13.17	41.96	25.76	1.15	0.63			0.87
V	*Juglans nigra* L.	470	79.84	52.34	185.88	131.04	5.30	3.93			0.48
	Total	823	98.92	65.51	227.84	156.80	6.45	4.56	66.22	59.68	1.35
VI	*Quercus rubra* L.	255	53.55	34.97	116.81	82.76	3.16	2.39			0.80
(Control)	*Juglans nigra* L.	191	51.07	35.52	182.76	140.64	6.58	5.25			0.23
	Total	446	104.62	70.49	299.57	223.40	9.74	7.64	100.00	100.00	1.03

relation between the dendromass production quantity and quality (Tokár, 1982a, b, 1991a, b, 1992a, b, 1993, 1996, 1998). For pure red oak stands, some authors (Réh, 1989, 1997; Štefančík, 1992) recommend strong thinning, because this method does not reduce the tree quality and it results in sooner reaching of the required assortment. According to Mittscherlich (1957) and Tokár (1991a, b, 1998) the first and second thinning should be moderate and the intensity of the following ones should be increased.

In conditions of floodplain forests, highly productive are also mixed stands of red oak and black walnut and mixed stands of black walnut and small-leaved linden (Fig 1). In these stands, the best growth, the highest production and the highest stem quality reaches the black walnut. For these stand types is recommended moderate crown thinning, with positive selection, repeated each five years, founded on selection and permanent marking of final-crop trees (Tokár, 1996, 1998). Final-crop trees are considered trees with bigger diameter and height than the stand mean diameter and height, having stem and crown quality corresponding to the first and the second quality degree. Their number should range between 250–300 pcs ha^{-1} (Tokár 1991a, b, 1992a, b, 1993, 1994a, b 1996, 1998).

Fig 1. Mixed stand of *Juglans nigra* L. and *Tilia cordata* Mill.

The obtained results show that the thinning most influenced growth characteristics of the mixed stand consisting of black walnut and small-leaved linden (PRP V) and the mixed stand consisting of black walnut and red oak in which the walnut representation was 80%. The highest weight stock of the above ground dendromass was reached in the tended mixed stand of black walnut (80%) and red oak (20%) on PRP I. Positive results were also reached in the pure black walnut stand on PRP IV (Fig 2). The volume stock of stands growing on the other PRP was lower compared with the control PRP, but the production quality was higher. The total volume and weight production of above ground dendromass in tended stands was also lower than on the control PRP VI.

Fig 2. Pure stand of *Juglans nigra* L.

The data on amount of chemical elements accumulated in soil and in above ground dendromass of various stand types of red oak and black walnut was processed by Tokár, (1992c, 1994c). The author identified certain relations between the content of elements in above ground dendromass and the stand type. The highest contents (kg ha^{-1}) of Mg (570), Ca (2,625) and K (1,053) were found in the above ground dendromass of the pure black walnut stand, of Na (543), Pb (1) and Fe (63) in the mixed stand of black walnut and small-leaved linden. The maximum content of Zn (52) was found in mixed stand of red oak and black walnut.

The amount of Ca, K, Mg, Na and Zn accumulated on PRP series Ivanka pri Nitre was higher, that of Pb and Fe lower compared with on PRP series Sikenica. The content of elements found in soils on PRP series Ivanka pri Nitre was also higher. On both PRP series, however, was rather high content of Ca found not only in dendromass but also in the soil. The reason of this phenomenon have not been recognised yet.

In orchard management the red oak and black walnut are utilised in park and street plantations. They have both high aesthetical qualities (leaf colour and shape, flowers and fruits) and phytoncide effects. Black walnut can be with success used also in planting of greenery around big fattening stations (stables).

Conclusions

In paper is evaluated the influence of moderate crown thinning on development of phytocoenoses and above ground dendromass of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) stands planted on the PRP series Ivanka pri Nitre.

At the stand age of 48 years, the highest stock of above ground dendromass was reached in the mixed stand of black walnut (20%) and small-leaved linden (80%) and in the mixed stand of black walnut (80%) and red oak (20%). Oak and linden create the medium and lower stand layer, which has favourable influence on stem quality and height growth of black walnut. Linden trees produce abundant litter that is rapidly decomposed and enriches the soil with nutrients profitable for the growth of black walnut.

In the stands of the introduced tree species naturally penetrated other 17 autochtonous species, 7 of them (41%) shrubs. In the herb layer consisting of 56 herb species, were present abundant indicators of the wetted edaphic-hydric order of geobiocoens, manifesting that the water regimen of the soils has not been disturbed substantially, either by hydromeliorative treatment of surrounding agricultural land or of the Nitra riverbed regulation.

The strong dominance of heminitrophilous to nitrophilous species indicates the presence of the nitrophilous edaphic-trophic order of geobiocoens, group of forest types Ulmeto-Fraxinetum carpineum (Ulmifraxineta carpini superiora) and forest type 954 Dry elm-ash forest with hornbeam.

The two introduced woody plants on the PRP series Ivanka pri Nitre fructify intensively. Their seeds can be used as in forest management as in planting of greenery of urban areas (street and park plantings) and farm buildings (stores, animal husbandry buildings) in warmer regions of South Slovakia.

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Vývoj fytocenóz a nadzemnej produkcie duba červeného (*Quercus rubra* L.) a orecha čierneho (*Juglans nigra* L.) na sérii TVP Ivanka pri Nitre

Súhrn

V práci sa hodnotí vplyv miernych úrovňových prebierok na vývoj fytocenóz a nadzemnej dendromasy porastov introdukovaných drevín *Quercus rubra* L. a *Juglans nigra* L. Za viac ako 40 rokov preniklo do pestovaných porastov 17 autochtónnych druhov drevín, z toho 7 (41 %) druhov krov. Vo fytocenózach tvorených 56 druhmi bylín sa hojne vyskytujú indikátori zamokreného edaficko-hydrického radu geobiocénov, ktoré dokazujú, že vodný režim pôd nebol hydromelioračnými úpravami pozemkov a toku rieky Nitra podstatne narušený. Geobiocenózy, v ktorých bola séria trvalých výskumných plôch založená, sú súčasťou nitrofilného radu, skupiny lesných typov Ulmeto-Fraxinetum carpineum a lesného typu 954 Suchá brestová jasenina s hrabom. Najvyššia zásoba nadzemnej dendromasy (686,81 $m^3\,ha^{-1}$, 486,50 t ha^{-1}) a najvyšší priemerný periodický prírastok (20,58 $m^3\,ha^{-1}\,rok^{-1}$, 14,18 t $ha^{-1}\,rok^{-1}$) sa dosiahol v 48 ročnom nevychovávanom poraste (orech čierny 80 %, dub červený 20 %), zatiaľ čo najvyšší index rastu objemovej zásoby (414,30 %) a najvyššie percento priemerného periodického prírastku (12,57 %) sa zistili vo vychovávanom poraste orecha čierneho (20 %) a lipy malolistej (80 %). Najvyšší index rastu hmotnostnej zásoby (526,85 %) a najvyššie prírastkové percento (17,07 %) sa zistilo v zmiešanom poraste orecha čierneho (80 %) a duba červeného (20 %). Najvyššia objemová zásoba nádejných stromov sa tiež zistila v nevychovávanom poraste (299,57 $m^3\,ha^{-1}$), kým najvyšší priemerný periodický prírastok (11,27 $m^3\,ha^{-1}\,rok^{-1}$) bol vo vychovávanom poraste duba červeného (80 %) a orecha čierneho (20 %). Najvyššia hmotnostná zásoba nádejných stromov (230,98 t ha^{-1}) a najvyšší hmotnostný priemerný periodický prírastok (10,68 t $ha^{-1}\,rok^{-1}$) boli zistené v zmiešanom poraste orecha čierneho (80 %) a duba červeného (20 %).

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