FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Effects of soil tillage and mulching on thermal performance of a luvisol topsoil layer

José A. Andrade[1], Carlos A. Alexandre[2], Gottlieb Basch[3]

[1, 2]Institute of Mediterranean Agricultural and Environmental Sciences, University of Évora, Geosciences Department, Apartado 94, 7002-522 Évora, Portugal, E-mail: zalex@uevora.pt; E-mail: cal@uevora.pt
[3]Institute of Mediterranean Agricultural and Environmental Sciences, University of Évora, Crop Science Department, P-7002-554 Évora, Portugal, E-mail: gb@uevora.pt

Abstract

Andrade, J.A., Alexandre, C.A., Basch, G. 2010. Effects of soil tillage and mulching on thermal performance of a luvisol topsoil layer. *Folia oecol.*, 37: 1–7.

Important heat transfer processes occurring on soil surface control the thermal environment within the topsoil layer and the boundary layer above. Soil management practices such as the application of mulches or the formation of a soil micro relief through tillage modify the thermal regime of soils. The aim of this study was to compare the effects of soil tillage and the application of stubble mulch and different amounts of straw mulch on the thermal behaviour of a luvisol. The experiments were performed from January to May 2007, in a field sown with winter wheat. Temperature was measured with copper-constantan thermocouples placed over straw and over stubble, at soil surface and at 2, 4 and 8 cm depths. Compared with tilled bare soil, the application of straw mulch seems to affect the soil thermal regime more significantly than that of stubble mulch. The topsoil under straw mulch showed the lowest thermal amplitudes and the highest minimum temperatures. From March to May, the mean temperatures in the profiles covered by straw were significantly lower than those recorded on the remaining plots. Implications of these techniques for soil temperature control in crop growing are discussed too.

Key words

crop establishment, soil temperature, soil tillage, straw mulch, stubble mulch

Introduction

Crop establishment is a major factor determining crop productivity in the field and is strongly controlled by soil temperature and soil moisture (Abreu, 1987; Andrade, 2001). Important heat energy transfers on soil surface control the thermal environment within the topsoil layer and the boundary layer above it (Arya, 1988). In practice, the soil thermal regime is usually modified by application of mulches and the creation of a soil micro-relief by tillage. Both methods affect net radiation and heat transfer on soil surface by means of affecting soil water evaporation (De Vries, 1975). Thus, investigation of the influence of surface treatments on soil thermal regime is useful for the evaluation of differences in the performance of crop growth and development.

Porous mulches such as straw or stubble mulches, affect soil moisture and soil temperature by influencing soil thermal parameters such as heat capacity, heat conductivity and vapour transport resistance (Sui et al., 1992; Bussière and Cellier, 1994). Although they may depress crop growth (Schaller and Evans, 1954; Van Wijk et al., 1959) by decreasing mean soil temperature, these mulches can help in the conservation of soil moisture, making it a very important practise in areas of low rainfall (Awan, 1964; Chakraborty et al., 2008). In addition, these mulches can be applied either to protect soil surface from excessive cooling or to avoid its excessive warming (Rosenberg et al., 1983; Nath and Sarma, 1992), having this latter feature special relevance in the context of the global warming (*IPCC*, 2007).

Extreme variations in soil temperature near the surface of bare soils and quick changes in soil water content due to irregular rainfall and high evaporative demands lead generally to poor crop establishment in Mediterranean areas (Abreu, 1987). Moreover, risks of frost are common either during the intermediate vegetative stages in winter crops or during the early stages in summer crops.

The aim of this study was to compare the effects of different types of soil surface treatments – soil tillage, stubble mulch and straw mulch applied in two different amounts, on the thermal performance of a Haplic Luvisol sown with a wheat crop. The results expected should enable us to discuss not only some possible consequences of soil and residue management for crop growth rates and the development of plants but also the risk of frost damage.

Material and methods

Field experiments were performed from January to May 2007 at Herdade da Revilheira, Reguengos de Monsaraz (lat.: 38º28' N; long.: 7º28' W), in a field sown with winter wheat (*Triticum aestivum* L.) in early December. The local climate is Csa, according to Köppen climate classification (Ahrens, 2003). At Reguengos de Monsaraz, about 5 km away from the experimental site, the mean annual temperature averages 16.1 ºC, ranging from a monthly mean of 8.7 ºC in January to 24.3 ºC in August, while the mean annual rainfall is 572 mm, 77.4% of which falls between October and March. According to the climate data supplied by a weather station located at the experimental site (*CGE*, 2009), mean monthly temperatures in March and April as well as the rainfall values in January and March were visibly lower than those correspondent Normal values but close to them in all the other cases (Table 1).

The soil was classified as Haplic Luvisol (*WRB SR*, 2006) and its profile was Ah-AB-Bt-C. The clay-loamy Ah (0–8 cm) and AB (8–24 cm) horizons had a bulk density of 1.51 ± 0.12 Mg m^{-3} and 1.58 ± 0.07 Mg m^{-3}, respectively, while the clayey Bt (24–53 cm) horizon had a bulk density of 1.63 ± 0.04 Mg m^{-3}. In the Ah horizon, soil water content was 0.21 ± 0.07 cm^3 cm^{-3} at 1500 kPa and 0.43 ± 0.13 cm^3 cm^{-3} at 30 kPa.

Soil temperatures were measured in four profiles with copper-constantan thermocouples connected to a data-logger (*data Taker* 600). One profile was subject to a surface soil tillage only (modality A), another was covered by stubble mulch (mod B) and the remainder were covered by two different amounts of straw mulch (mod C – 2,500 kg ha^{-1} and mod D – 5,000 kg ha^{-1}). Thermocouples were placed at the middle of each profile, at its surface, at 2, 4 and 8 cm depth and over straw and stubble mulches. Hourly averaged temperatures were recorded for all thermocouples locations. Effects on soil thermal regime were evaluated by daily mean temperatures and daily minimum temperatures at 2 cm depth as well as by thermal amplitudes at 2 cm, at 4 cm depth and at the surface of the mulch.

Soil water contents were measured four times (1st March, 15th March, 28th March and 13th April) by the gravimetric method down to 20 cm depth, in each of the four plots. Crop height was also measured four times (1st March, 15th March, 13th April and 5th May) on five plants randomly chosen in each plot/modality.

Statistical differences between means were tested at 5% significance level (*$P < 0.05$) with paired Student's t-tests using least significant differences (LSD) procedures (Walpole and Myers, 2006).

Results

Soil moisture

Table 2 shows soil water contents measured on four dates in each of the four plots. Soil water content was about 50% of the available capacity (AC) either on the first date or on the last date, about 20–30% of the AC on the second and close to the wilting point on the third. At all dates, plots corresponding to the modalities C and D presented generally the highest contents of soil water while those referred to the others (A and B) presented the smallest values. Differences observed between the values found under straw mulch and those found under stubble mulch or tilled soil were about 0.02–0.03 cm^3 cm^{-3} at all dates and were statistically significant (*$P < 0.05$). On the other hand, neither the amount of

Table 1. Mean monthly air temperature [ºC] and monthly rainfall [mm] data recorded at Herdade da Revilheira, from January to May 2007 (in brackets, the corresponding Normal values referred to the period 1961–1990)

	Jan	Feb	Mar	Apr	May
Air temperature [ºC]	7.7 (8.7)	10.8 (10.0)	11.4 (12.6)	12.5 (14.2)	17.0 (17.3)
Rainfall [mm]	36.8 (77.6)	95.6 (76.7)	11.6 (83.3)	49.7 (44.9)	38.9 (33.5)

Table 2. Soil water contents ($cm^3\ cm^{-3}$) measured four times (1st March, 15th March, 28th March and 13th April) on four plots (modalities A, B, C and D)*

	Modality A	Modality B	Modality C	Modality D
1st March	0.33 ± 0.012	0.32 ± 0.035	0.37 ± 0.051	0.34 ± 0.053
15th March	0.27 ± 0.025	0.25 ± 0.025	0.28 ± 0.031	0.29 ± 0.004
28th March	0.20 ± 0.045	0.21 ± 0.053	0.24 ± 0.049	0.22 ± 0.039
13th April	0.30 ± 0.012	0.27 ± 0.012	0.32 ± 0.012	0.30 ± 0.018

*modality A: tilled soil; modality B: stubble mulch; modality C: straw mulch (2,500 kg ha^{-1}); modality D: straw mulch (5,000 kg ha^{-1})

straw mulch seems to affect significantly the soil water content nor stubble mulch seems to have any effect on it when compared with tilled soil. These results also show the usefulness of straw mulch in conservation of soil water pointed out by several authors, as Nath and Sarma (1992) and Ramakrishna et al. (2006).

Crop height

Table 3 shows measurements of crop heights (in cm) at four different dates, corresponding to the four modalities in study. The highest mean crop height was always found in the plot where the biggest amount of straw mulch was applied (mod D). On the contrary, the smallest crop height was found in mod A at the first date (1 Mar), in mod B at the last one (4 May) and in the others (mod A and mod C) on 15th March and 13th April. Differences between the highest and the smallest mean values ranged from 14 cm on 1st March to 9–10 cm in the remaining dates.

Mean soil temperatures

Daily mean temperatures ($\overline{T}_{day}$) at the 2 cm depth ranged from about 3–4 ºC (end of January) to 23–28 ºC (middle of May), following closely the annual course of net radiation at the soil surface in areas of Mediterranean climates (Fig. 1). In January and February, differences between daily mean temperatures recorded in the four plots either at 2 cm or at 4 cm depth (not shown) were not generally greater than 1 ºC, while from March to May the plots covered by straw presented mean temperatures significantly lower than those covered by stubble mulch or subject to surface tillage, often reaching about 3–4 ºC or even more in some days. On a decennial basis (periods of ten days) these differences were statistically significant (*$P < 0.05$) during this period. In addition, the differences recorded during these last two months are more pronounced during warming periods than when mean daily temperatures decreased.

On the other hand, the increase of mean temperatures in soil profiles covered by straw (mod C and mod D), follows with some delay, mainly in April and May, the increase verified in the other profiles (mod A and mod B). This is probably due to the higher water holding capacity presented by straw mulch when compared with those presented by the other profiles. Furthermore, neither the amount of straw mulch seems to affect at topsoil layer, nor the maintenance of stubble mulch over soil surface seems to change significantly when compared with tilled soil only.

Daily minimum temperatures recorded at 2 cm depth were lower in profiles covered by stubble or subject to a surface tillage than in profiles covered by straw mulches, irrespective of their densities (Fig. 2). Differences between minimum temperatures recorded in modalities B (stubble mulch) and D (straw mulch – 5,000 kg ha^{-1}) were about 2 ºC (= 2.20 ± 1.05 ºC) on average, reaching up to 4–5 ºC at maximum. In a decennial basis (periods of ten days) these differences were statistically significant (*$P < 0.05$) during this period, except in the middle of January and April. Differences between minimum temperatures recorded in modalities C and D were generally lower than 1 ºC (= 0.63 ± 0.43 ºC), meaning that prevention of frost deposition on soil surface doesn't seem to depend significantly on the amount of straw mulch; in the same way, differences found between modalities A and B (= 0.54 ± 0.47 ºC) means that stubble

Table 3. Mean crop (winter wheat) heights [cm], measured on each of the four plots (modalities A, B, C and D) on four different dates (1st March, 15th March, 13th April and 4th May)*

	Modality A	Modality B	Modality C	Modality D
1st March	36 ± 2.0	45 ± 2.5	41 ± 0.7	50 ± 1.6
15th March	51 ± 2.5	55 ± 3.2	50 ± 1.6	59 ± 2.2
13th April	68 ± 3.7	73 ± 2.7	68 ± 3.2	78 ± 2.9
4th May	80 ± 3.8	75 ± 2.5	80 ± 3.5	85 ± 3.2

*modality A: tilled soil; modality B: stubble mulch; modality C: straw mulch (2,500 kg ha^{-1}); modality D: straw mulch (5,000 kg ha^{-1})

mulch doesn’t increase protection against frost deposition when compared with tilled soil only.

Damping of thermal wave

Damping of thermal wave down to 4 cm depth was significantly higher in modality D (densest straw mulch) than in the remaining plots, while the lowest damping was found in the plots where stubble was applied (Fig. 3). In addition, damping of thermal wave was higher in mod C than in mod A. Mean differences between soil thermal amplitudes found in modalities C and D and those found in modalities A and B, either at 2 cm or at 4 cm depth, ranged from about 7 ºC to about 10 ºC, meaning that straw mulch is much more effective in damping the thermal wave into depth than the stubble mulch or the tilled soil only.

Amplitudes at 4 cm depth of soil profile covered by straw mulch (mod D) were about half ($\Delta T_{modD}/\Delta T_{modB}$ = 0.48 ± 0.09) of those verified in the soil profile covered by stubble mulch (mod B). The ratio between thermal amplitudes verified at 4 cm depth in tilled soil and those verified in the profile covered by stubble mulch ($\Delta T_{modA}/\Delta T_{modB}$) varied from 0.90 to 0.71 (0.86 ± 0.11), while that verified in covered profiles by straw ($\Delta T_{modD}/\Delta T_{modC}$) ranged from 1.05 to 0.72 (0.77 ± 0.13).

Thermal amplitudes at 2 cm depth were 44 ± 7% and 23 ± 4% of those observed at the top of the straw mulch layer, respectively in modalities C and D. On the contrary, stubble mulch damped the thermal wave in about 21 per cent only, i.e., the amplitudes at 2 cm depth are 79 ± 10% of those observed at the surface (Fig. 4). Since no trend was visible on the time course of the relationships plotted in Fig. 4, the damping of heat wave into the soil did not seem to be significantly affected neither by crop growth nor by the annual course of net radiation.

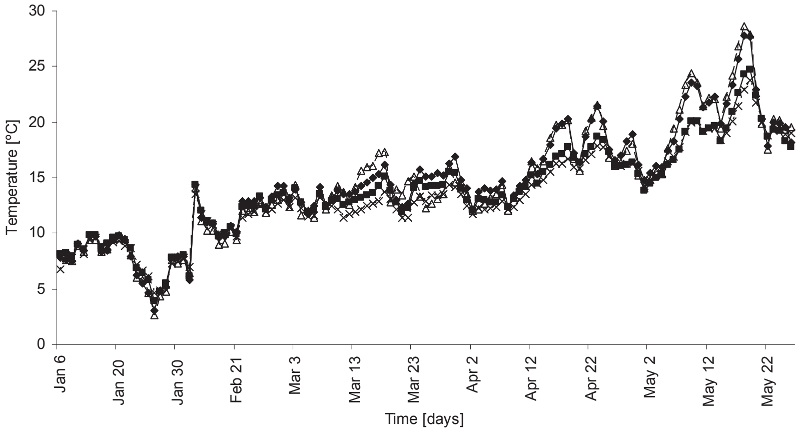


Fig. 1. Daily mean temperatures recorded at a 2 cm depth, from January to May 2007: modality A: tilled soil (—•—); modality B: stubble mulch (---Δ---); modality C: straw mulch – 2,500 kg ha^{-1} (—■—); modality D: straw mulch – 5,000 kg ha^{-1} (---x---)

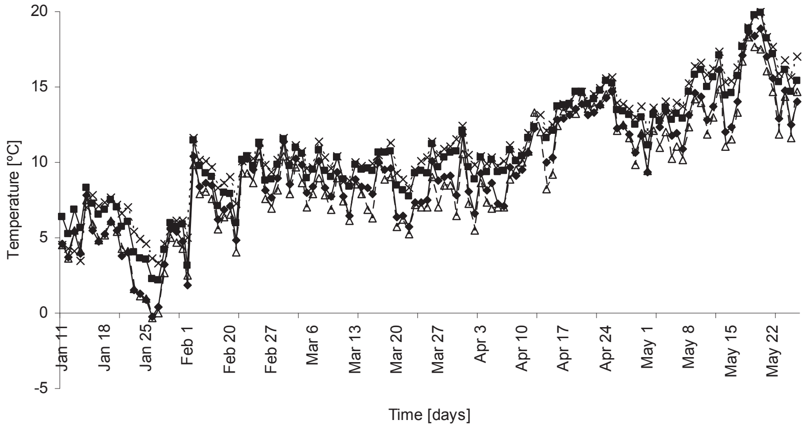


Fig. 2. Daily minimum temperatures recorded at a 2 cm depth, from January to May 2007: modality A: tilled soil (—•—); modality B: stubble mulch (---Δ---); modality C: straw mulch – 2,500 kg ha^{-1} (—■—); modality D: straw mulch – 5,000 kg ha^{-1} (---x---)

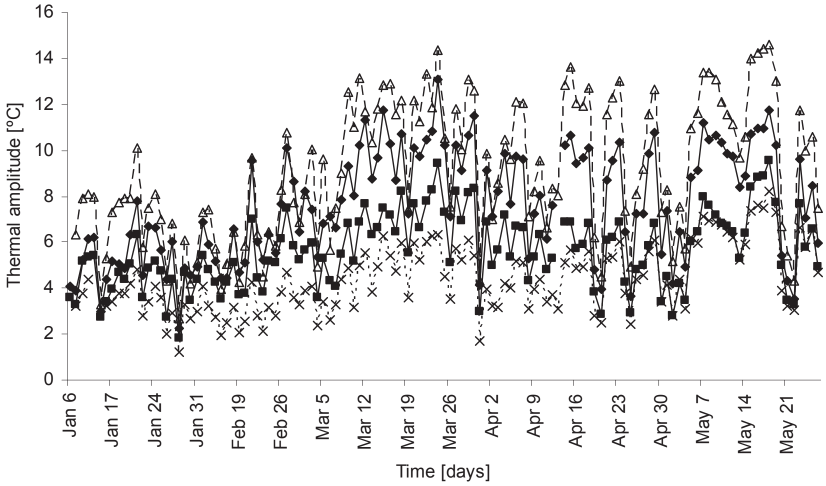


Fig. 3. Temperature amplitudes at a 4 cm depth, from January to May 2007: modality A: tilled soil (—•—); modality B: stubble mulch (---Δ---); modality C: straw mulch – 2,500 kg ha^{-1} (—■—); modality D: straw mulch – 5,000 kg ha^{-1} (---x---)

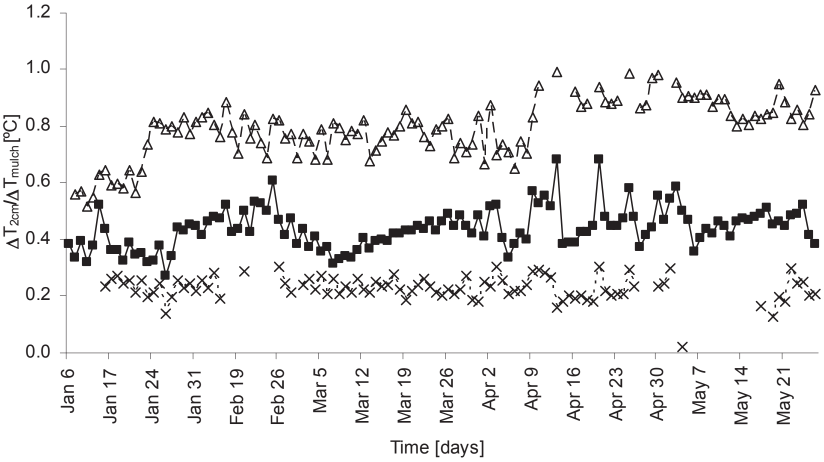


Fig. 4. Ratio thermal amplitudes at a 2 cm depth/thermal amplitudes over mulch, from January to May 2007: modality B: stubble mulch (---Δ---); modality C: straw mulch – 2,500 kg ha^{-1} (—■—); modality D: straw mulch – 5,000 kg ha^{-1} (---x---)

Discussion

Soil temperature is of utmost importance in the early development of grass crops because their apical meristem is below the soil surface till the 5–6 first unfolded leaves (ANDRADE, 2001; CHEN, 2007). Comparing with tilled bare soil, the application of straw mulch seems to affect more significantly the soil thermal regime than that of stubble mulch. This fact was evident both with regard to mean and minimum daily temperatures and the damping of the thermal wave into the soil profile. On the contrary, no significant differences were found between the parameters measured in the plot covered by stubble mulch and those measured in tilled soil only. The effect of straw mulch is similar to that of a litter layer in pine stands (ANDRADE et al., 1993), both favouring the soil water retention and decreasing of thermal amplitudes in the topsoil.

Since the decreasing of mean temperatures was more visible in soil profiles covered by straw mulch than in soil profiles covered by stubble mulch or tilled only, mainly when temperatures are higher (after March–April in Mediterranean climates in Northern hemisphere), the rhythm of the latest development stages of winter crops (booting, heading, flowering, grain filling and stage, maturity stages) should be more affected than their early development under these conditions. On the contrary, all the development stages of summer crops should be affected by the incorporation in soil profile of this type of mulch.

On the other hand, the decreasing in soil temperature due to the application of straw mulch did not seem to affect crop growth. In fact, the highest values for crop height were even found in the plots of modality D (Table 3), probably due to the higher soil water contents retained under straw mulch (especially that of highest density) (Table 2). Thus, any delay in crop development seems to be compensated by a stronger growth.

Straw mulch seems to be more efficient to avoid damage due to frost deposition on soil surface than the other modalities (A and B) while the maintenance of stubble on soil surface does not seem to provide the thermal moderating effect of the straw mulch layer.

In spite of its influence on damping of thermal wave into soil surface, the amount of straw do not affect significantly the accumulation of temperature (degrees-day) by crops and hence the rhythm of their development. However, the amount of straw mulch seems to affect crop height which might be related to the higher capacity to hold water in profiles covered with high densities of straw mulches (in the case, 5,000 kg ha^{-1}).

Conclusions

The more evident is the soil warming that reflects the annual course of net radiation, the more evident is the cooling as a result of the application of straw. The application of straw mulch at the soil surface increases daily minimum temperatures in the topsoil layer by about 2º C, avoiding often the occurrence of frost in the very topsoil layer. Despite the lack of significance of the influence of the amount of straw mulch on daily mean and minimum temperatures, it affects significantly the damping of thermal wave into topsoil layer. The maintenance of stubble mulch at the soil surface is not an efficient practice to decrease thermal variations in the topsoil layer.

Acknowledgement

The authors acknowledge the support by the European Union (FEDER) through the Foundation for Science and Technology (FCT): project POCTI/AGG/46545/2002.

References

ABREU, F.G. 1987. *Influence of atmospheric saturation deficit on early growth of groundnut.* PhD thesis. Nottingham: Nottingham University. 249 p.

AHRENS, C.D. 2003. *Meteorology Today:* an introduction to weather, climate, and the environment. Pacific Grove, CA: Thomoson/Brooks/Cole.

ANDRADE, J. 2001. *Temperatura do solo (e análise de Fourier), humidade do solo e desenvolvimento inicial de várias culturas em solos Pmg e Cb* [Soil temperature (Fourier analysis), soil moisture and initial development of various cultures in Pmg and Cb soils]. PhD thesis. Évora: Universidade de Évora. 341 p.

ANDRADE, J.A., ABREU, F.G., MADEIRA, M.V. 1993. *Aplicação do modelo sinusoidal à variação da temperatura do solo em condições de solo nu e sob coberto* [Application of a sinusoidal model on variations in soil temperature in bare and covered soils]. *Anais Inst. sup. Agron.*, 43: 233–253.

ARYA, S. P. 1988. *Introduction to micrometeorology.* San Diego: Academic Press. 307 p.

AWAN, A.B. 1964. Influence of mulch on soil moisture, soil temperature and yield of potatoes. *Amer. Potato J.*, 41(10): 337–339.

BUSSIÈRE, F., CELLIER, P. 1994. Modification of soil temperature and water content regimes by a crop residue mulch: experiment and modelling. *Agric. Forest Meteorol.,* 68:1–28.

CHEN, S.Y., ZHANG, X.Y., PEI, D., SUN, H.Y., CHEN, S.L. 2007. Effects of straw mulching on soil temperature, evaporation and yield of winter wheat: field experiments on the North China Plain. *Ann. Appl. Biol.*, 150 (3):261–268.

CGF (Centro de Geofisica de Évora) [The Centre of Geophysics of Évora]. 2009. [cit. 2009-12-15]. <http://www.cge.uevora.pt/cge/observacoes-e-dados.html>

CHAKRABORTY, D., NARGARAJAN, S., AGGARWAL, P., GUPTA, V.K., TOMAR, R.K., GARG, R.N., SAHOO, R.N., SARKAR, A., CHOPRA, U.K., SUNDARA SARMA, K.S., KALRA, N. 2008. Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment. *Agric. Wat. Mgmt*, 95: 1323–1334.

DE VRIES, D. A. 1975. Heat transfer in soils. In DE VRIES, D.A. and AFGAN, N.H. (eds). *Heat and mass transfer in the biosphere*. Washington D.C: Scripta Book Company, p. 5–28.

IPCC Fourth Assesment Report. 2007. [cit. 2010-01-15]. <http://www.ipcc.ch/ipccreports/ar4-syr.htm>.

NATH, J.C., SARMA, R. 1992. Effect of organic mulches on growth and yield of Assam lemon (Citrus limon Burm.). *Hort. Res.*, 5: 19–23.

RAMAKRISHNA, A, HOANG, M.T., WANI, S.P., TRANH, D., L. 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Res.*, 95 (2–3): 115–125.

ROSENBERG, N., BLAD, B.L., VERMA, S.B. 1983. *Microclimate. The biological environmental*. New York: John Wiley & Sons. 528 p.

SCHALLER, F.W., EVANS, D.D. 1954. Some effects of mulch tillage. *Agr. Engng*, 35: 731–734.

SUI, H., ZENG, D., CHEN, F. 1992. A numerical model for simulating the temperature and moisture regimes of soil under various mulches. *Agric. Forest Meteorol.* 61: 281–299.

VAN WIJK, W.R., LARSON, W.E., BURROWS, W.C. 1959. Soil temperature and the early growth of corn from mulched and unmulched soil. *Soil Sci. Soc. Amer. Proc.*, 23: 428–434.

WRBS (World Reference Base for Soil Resources). 2006. World Soil Resources Report, 103. Rome: FAO-ISRIC-ISS. 145 p.

Walpole, R.E., Myers R.H., Myers, S.L. 2006. *Probability and statistics for engineers and scientist*s. New Jersey: Prentice Hall. 665 p.

Vplyv orby a mulčovania na teplotný režim vo vrchných vrstvách pôdy

Súhrn

Významné procesy toku tepla na povrchu pôdy určujú tepelné pomery v povrchovej vrstve pôdy ako aj v hraničnej vrstve nad pôdnym povrchom. Postupy používané v pôdohospodárstve – ako je mulčovanie a modelovanie mikroreliéfu pomocou orby modifikujú teplotný režim pôd. Cieľom tejto práce je porovnať účinky orby a strniska ako aj rozličných množstiev slameného mulču aplikovaného na pôdu na tepelný režim luvisolov. Experimenty prebiehali na poli osiatom ozimnou pšenicou, od januára do mája 2007. Teplota bola meraná pomocou medeno-konštantánových článkov, umiestnených vždy v súboroch – nad slamou a nad strniskom, na povrchu pôdy a v pôde v 2, 4 a 8 cm. Ukázalo sa, že slamený mulč aplikovaný na holú oráčinu ovplyvňoval teplotný režim pôdy významnejšie ako ponechané strnisko. V povrchovej vrstve pôdy boli zistené najmenej výrazné teplotné amplitúdy a najvyššie minimálne teploty. Od marca do mája boli priemerné teploty zaznamenané v pôdnych profiloch pokrytých slamou významne nižšie ako na plochách ošetrených iným spôsobom. V práci sa uvádza aj možné využitie týchto prístupov za účelom kontroly pôdnej teploty pri pestovaní plodín.

Received March 3, 2010
Accepted March 24, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

N_2O fluxes from agricultural soils in Slovakia and Russia – direct measurements and prediction using the DNDC model

Eugene Balashov[1], Ján Horák[2], Bernard Šiška [2], Natalya Buchkina[1], Elena Rizhiya[1], Sergey Pavlik[1]

[1]Agrophysical Research Institute of the Russian Academy of Agricultural Sciences, 14 Grazhdansky prospekt,
St. Petersburg 195220, Russia, E-mail: Eugene_Balashov@yahoo.co.uk
[2]Department of Biometeorology and Hydrology, Slovak University of Agriculture in Nitra, Hospodárska 7,
949 01 Nitra, Slovakia, E-mail: Bernard.Siska@uniag.sk

Abstract

Balashov, E., Horák, J., Šiška, B., Buchkina, N., Rizhiya, E., Pavlík, S. 2010. N_2O fluxes form agricultural soils in Slovakia and Russia – direct measurements and prediction using the DNDC model. *Folia oecol*., 37: 8–15.

Direct measurements of N_2O emissions were made on a loamy sand Spodosol (Russia) on agricultural plots with spring barley (*Hordeum vulgare* L.), potato (*Solanum tuberosum* L.), and white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) during the growing seasons of 2004 and 2006. A closed chamber method was used for measurements of N_2O fluxes from the soil. The DNDC model was applied to predict N_2O emissions from agricultural soils in the Danubian Lowland in Slovakia and in a northwestern region of Russia. Comparison of the modeled against the observed data demonstrated that the DNDC model adequately predicted the N_2O fluxes from soils in Russia and was sensitive to precipitation, soil water-filled pore space and rates of N fertilizers. A comparison of the modeled N_2O cumulative fluxes from soils in Slovakia and Russia showed that the DNDC model could be applied for the prediction of their seasonal dynamics in the selected agricultural sites.

Key words

agricultural soils, DNDC model, N_2O emission

Introduction

N_2O is a greenhouse gas whose emission needs to be quantified by Slovakia and Russia according to the Kyoto protocol. Emission of this gas from agricultural soils is regulated by several key properties such as soil moisture, temperature, mineral nitrogen (N), available soil organic carbon (SOC) and pH, and is always varying in space and time (Dobbie et al., 1999). N_2O is produced by microorganisms through nitrification and denitrification. Addition of N with mineral fertilizers and manure increases the N_2O emission from soils (Smith et al., 1998; Buchkina et al., 2006).

Nitrous oxide (N_2O) emissions from agriculture reach approximately 70% of annual global N_2O emissions (Mosier, 2001). Among the environmental and anthropogenic pressures, which account for the increased N_2O emissions from agriculture, it is necessary to distinguish precipitation, temperature, fertilisers, soil compaction, animal grazing and erosion processes. In the recent years scientists have already undertaken successful attempts to estimate the N_2O emissions from agricultural soils and to establish a validate basis for national agricultural policies on a reasonable application of mineral and organic fertilisers.

Process-based models of C and N biogeochemical cycling are powerful tools in agro-ecosystem studies. Among these models, the DNDC (Denitrification-

Decomposition) model showed a distinguished capacity for predicting soil organic C dynamics and N_2O, NO, NH_3, CO_2 and CH_4 emissions from soils (Li et al., 1992; Li, 2000). In Slovakia and Russia, the DNDC model is at present used for assessing the environmental and anthropogenic impacts on N_2O emissions from agricultural soils. The DNDC model can simulate the trace gas emissions from agriculture at a site level and at a regional level. At the site level, the model predicts the N_2O emissions from selected locations and, therefore, can be validated against measured N_2O emissions from a cropping system in an agricultural region. Using the validation records, the DNDC model's sensitivity and capacity of predicting trace gas emissions can be assessed for other similar cropping systems in regions with similar climatic conditions. The objectives of the present studies were to:

1. Compare between the modeled and measured N_2O fluxes from an agricultural soil in Russia
2. Compare the modeled N_2O fluxes from soils on selected agricultural sites in Slovakia and in Russia.

Material and methods

The study sites were located on a loamy sand Spodosol in a northwestern region of Russia and on a sandy loam Cambisol in the Danubian Lowland in Slovakia. Our studies were carried out on agricultural sites with different crop types and nutrient conditions. These sites represented agro-ecosystems typical for these regions of both countries.

Soil properties, weather conditions, and soil management in the Danubian Lowland have been well documented by Horák and Šiška (2006). A rate of nitrogen fertilizers was 37.5 kg N ha^{-1} for sugar beet (*Beta vulgaris* var. *saccharifera* L. cv. Intera) and spring barley (*Hordeum vulgare* L. cv. Ebson) for the growing seasons of 2000 and 2001, respectively. The total amount of precipitation was equal to 132 mm and 267 mm for growing periods of spring barley and sugar beet, respectively. A dynamics of precipitation during the growing seasons of sugar beet (2000) and spring barley (2001) in Slovakia is presented in Fig. 1.

In the NW Russia, experimental studies were carried out at the Menkovo experimental station (59°34' N, 30°08' E) of the Agrophysical Research Institute in the St. Petersburg region of Russia during the growing seasons of 2004 and 2006. The study sites were agricultural plots planted with spring barley (*Hordeum vulgare* L. cv. Suzdalets), potato (*Solanum tuberosum* L. cv. Nevsky), and white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L. cv. Kolobok). Rates of N fertilizers were: 0; 65 and 110 kg N ha^{-1} for spring barley and 120 kg N ha^{-1} for potato in 2004, and 0; 70; 110 kg N ha^{-1} for white head cabbage in 2006. The dynamics of precipitation during the growing seasons of spring barley (2004), potato (2004) and white head cabbage (2006) in the NW Russia is presented in Fig. 1.

In our field studies, a closed chamber method was used for measurements of direct N_2O emission from soils two-three times a week (between noon and 2 pm) through the growing seasons of the crops (Buchkina et al., 2006). We used PVC chambers for each of the plots with the selected crops. Chambers were made of inverted cylindrical plastic buckets, 18.9 cm in diameter and 11 cm high. The chambers were pressed into the soil to a depth about 2 cm. Four chambers were used in each plot with spring barley and eight chambers were used on plots with potato and white head cabbage – four in the furrows and four on the ridges. The chambers were placed in a center of the ridge and the furrow (Fig. 2).

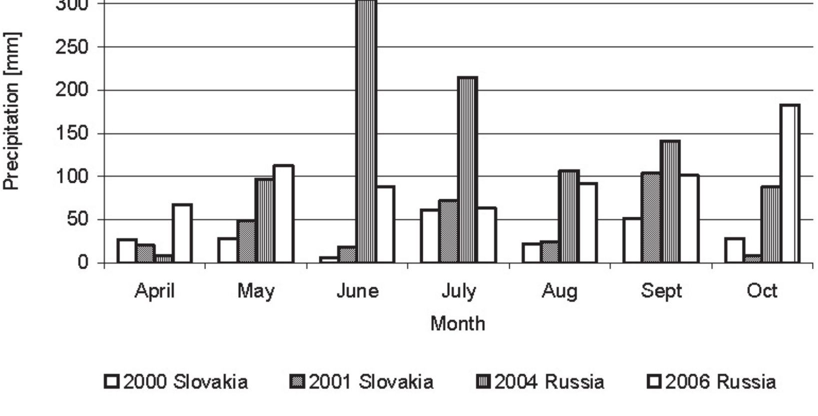


Fig. 1. Dynamics of precipitation during the growing season of sugar beet (*Beta vulgaris* var. *saccharifera* L.) in 2000 (Slovakia), spring barley (*Hordeum vulgare* L.) in 2001 (Slovakia) and 2004 (Russia), potato (*Solanum tuberosum* L.) in 2004 (Russia) and white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) in 2006 (Russia)

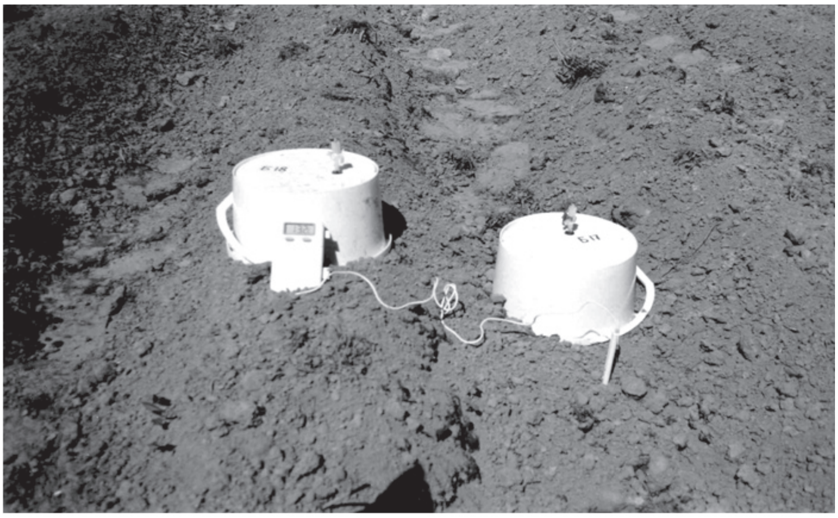


Fig. 2. Chamber placement on the ridges and in the furrows of the potato (*Solanum tuberosum* L.) plots in 2004 at the Menkovo experimental station (Russia)

Gas samples were taken by syringes from a headspace of the chambers via a three-way tap on the top of each chamber. N_2O concentrations in the gas samples, placed into hermetically closed glass vials (10 cm^3), were measured with a gas chromatograph fitted with an electron capture detector. Soil temperature and moisture content was simultaneously determined in each gas sampling. Measurements of soil bulk density, pH (H_2O), content of soil organic carbon (SOC), mineral nitrogen (NO_3^-, NH_4^+), and water were regularly made by conventional methods during the growing seasons. Air temperature and precipitation was measured daily. All of the soil analyses were conducted in three replicates. The means were calculated for selected parameters within each of the plots based on results of analytical measurements. Significance of differences between the means was tested by analysis of variance (one-way ANOVA) at $p \leq 0.05$. Relationships between soil parameters were assessed with a linear regression analysis using a computer statistical package at $p \leq 0.05$. The DNDC model (version 9.1) was used in our studies.

Results and discussion

There were several key factors affecting direct N_2O fluxes from the loamy sand Spodosol during the growing seasons of selected crops in years 2004 and 2006. The first factor was the amount of precipitation. The total amount of precipitation reached 690 mm and 769 mm during the growing seasons of spring barley and potato in 2004, and it was equal to 467 mm during the growing season of white head cabbage in 2006. A high amount of precipitation can cause a formation of soil anaerobic conditions favorable for microbial process of denitrification. Therefore, N_2O fluxes from soil can drastically increase if a water-filled pore space (WFPS) exceeds 60% (i.e. anaerobic conditions) after heavy rainfall events (Dobbie et al., 1999).

During the growing seasons in 2004, the precipitation-induced WFPS varied in the soil of plots with spring barley from 20.9% to 70.4%, while the WFPS in the soil of ridges and furrows on plots with potato ranged from 21.0% to 45.9% and from 21.0% to 85.7%, respectively. In our studies, strong positive correlations were observed between N_2O emission (Fig. 3a) and WFPS in the soil with spring barley without N fertilizers ($r = 0.71$, $p < 0.05$), and with the rates of N fertilizers applied in amounts of 65 kg N ha^{-1} ($r = 0.81$, $p < 0.01$) and 110 kg N ha^{-1} ($r = 0.78$, $p < 0.05$) during the growing season. On the plots with potato, there were observed weak correlations between N_2O emission (Fig. 3b) and WFPS in the ridges ($r = 0.28$), as aerobic conditions dominated in this soil zone. In the furrows of potato plots, anaerobic conditions were dominant, especially after rainfall events. Therefore, correlations between N_2O emission and WFPS were stronger in the furrows ($r = 0.59$, $p > 0.10$) than in the ridges, as WFPS played a more important role ($r = -0.81$, $p < 0.01$) in a decrease of NO_3^- concentration from 24.8 mg N kg^{-1} soil to 5.0 mg N kg^{-1} soil due to higher denitrification.

In the field experiments with white head cabbage, we studied the seasonal dynamics of N_2O emission in soils differing in fertility. In the soil with poor and rich fertilities, values of pH, SOC and total mineral N (as NO_3^--N + NH_4^+-N) content were equal to 5.6, 17.0 g C kg^{-1} soil, 19.8 mg N kg^{-1} soil and 6.1, 21.0 g C kg^{-1} soil, 30.4 mg N kg^{-1} soil, respectively.

Our results demonstrated that the seasonal N_2O emission also adequately responded to the precipitation events during the growing season of white head cabbage grown on the loamy sand Spodosol with low and high fertility, without and with application of N fertilizers in rates of 70 and 110 kg N ha^{-1} (Fig. 4a, b).

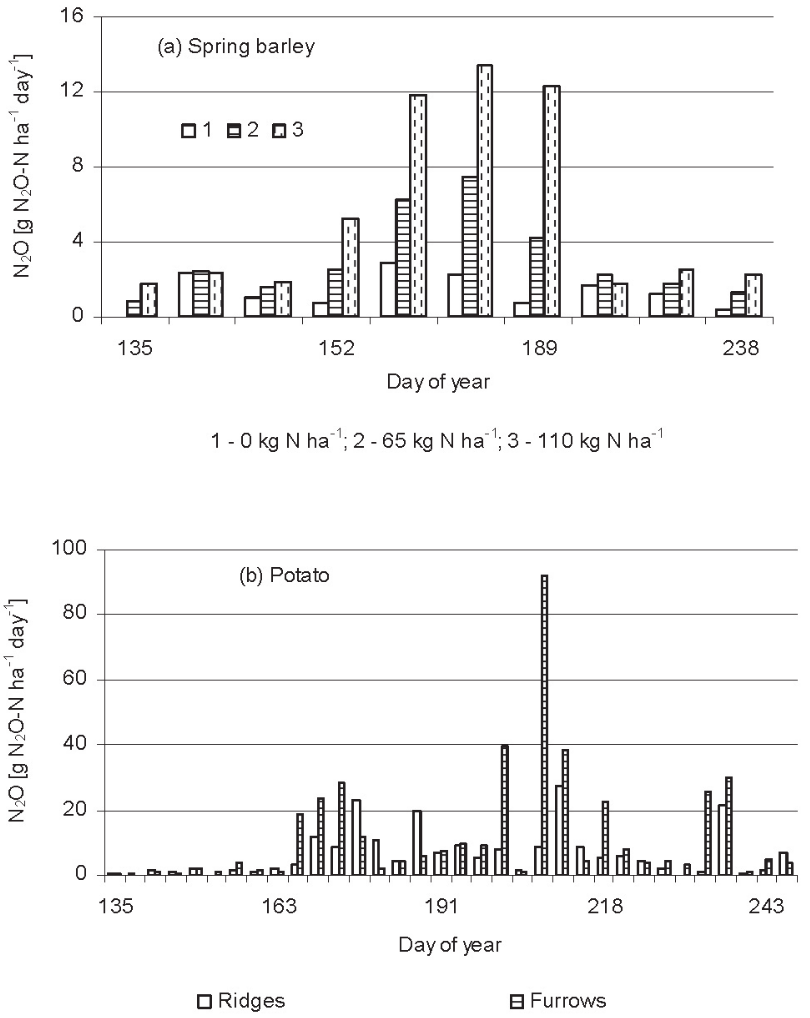


Fig. 3a, b. Dynamics of N_2O emission from loamy sand Spodosol under (a) spring barley (*Hordeum vulgare* L.) and (b) potato (*Solanum tuberosum* L.) at the Menkovo experimental station in 2004 (Russia)

The second factor of influence on N_2O emission was N fertilizers. The N_2O fluxes from the soil with spring barley increased with increasing rates (0–110 kg N ha^{-1}) of N fertilizers (Fig. 4a, b). The increasing rates of N fertilizers additively affected a total amount of soil mineral N (as NO_3^--N + NH_4^+-N), which varied from 7.9 to 76.1 mg N kg^{-1} soil (spring barley, 0 kg N ha^{-1}), from 10.5 to 139.3 mg N kg^{-1} soil (spring barley, 65 kg N ha^{-1}), and from 7.4 to 306.2 mg N kg^{-1} soil (spring barley, 110 kg N ha^{-1}) during the growing season of spring barley. Therefore, the soil with higher amount of available mineral N had more favorable conditions for microbial processes of nitrification and denitrification (Dobbie et al., 1999; Smith et al., 1998).

Our results showed that the DNDC adequately predicted the seasonal dynamics of N_2O cumulative fluxes from soil under spring barley with rates of N fertilizers of 65 and 110 kg N ha^{-1}, and under potato in the ridges. The differences (y, %) between the modeled (mod) and measured (meas) N_2O cumulative fluxes (F) were calculated according to the equation: $y = (Fmod - Fmeas)/Fmeas \times 100$. The differences between the modeled and measured N_2O cumulative fluxes, in terms of their final absolute values, changed from negative (at the rates of 0 and 65 kg N ha^{-1}) to positive ones (at the rate of 110 kg N ha^{-1}) for spring barley. In the case of potato, the differences between the modeled and measured records were higher for the furrows than for the ridges (Fig. 5).

The DNDC model was not able to adequately detect the formation of the above-mentioned anaerobic conditions in the furrows of potato plots.

In the case of white head cabbage, the lowest difference (–3%) between the modeled and measured N_2O cumulative fluxes was observed for the plot with rich soil without supplying N fertilizers. The modeled N_2O emission, compared to the measured ones, was much more sensitive to some precipitation events during the growing season of white head cabbage on the poor and rich soils amended with mineral N fertilizers (Fig. 6).

Therefore, the differences between the predicted and measured N_2O cumulative fluxes from the soil under white head cabbage could reach very high values (Fig. 7).

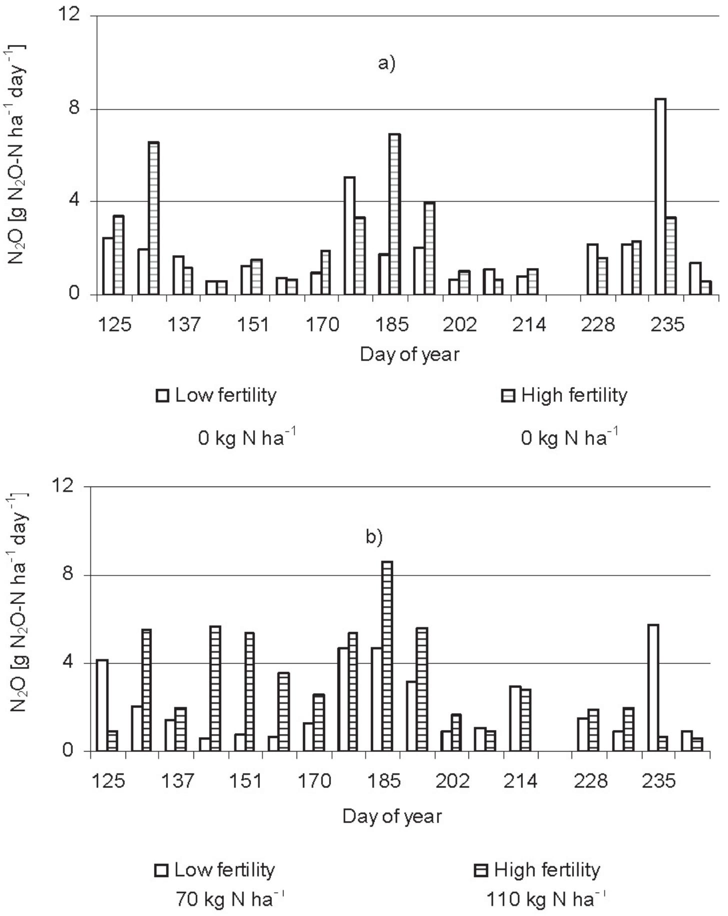


Fig. 4a, b. Dynamics of N_2O emission from loamy sand Spodosol with low and high fertility without (a) and with (b) application of N fertilizers for white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) at the Menkovo experimental station in 2006 (Russia)

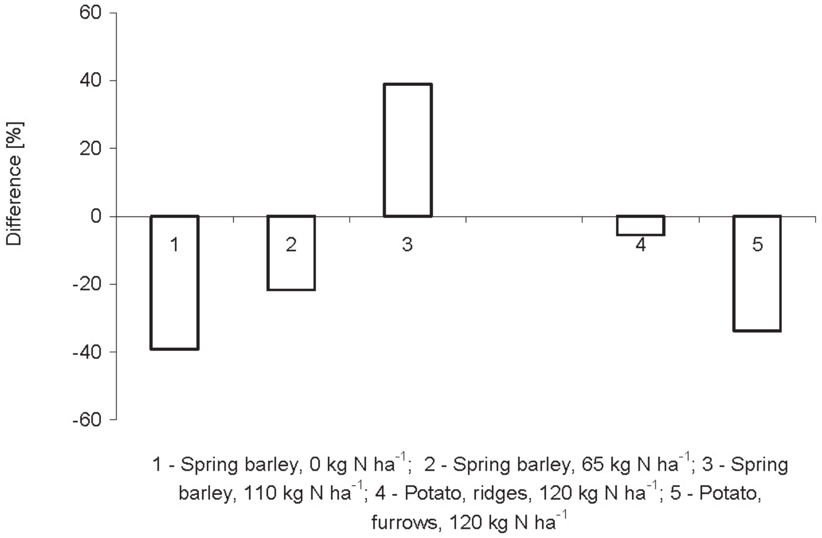


Fig. 5. Differences between the modeled and the measured N_2O cumulative fluxes from loamy sand Spodosol under spring barley (*Hordeum vulgare* L.) and potato (*Solanum tuberosum* L.) in ridges and furrows at the Menkovo experimental station in 2004 (Russia)

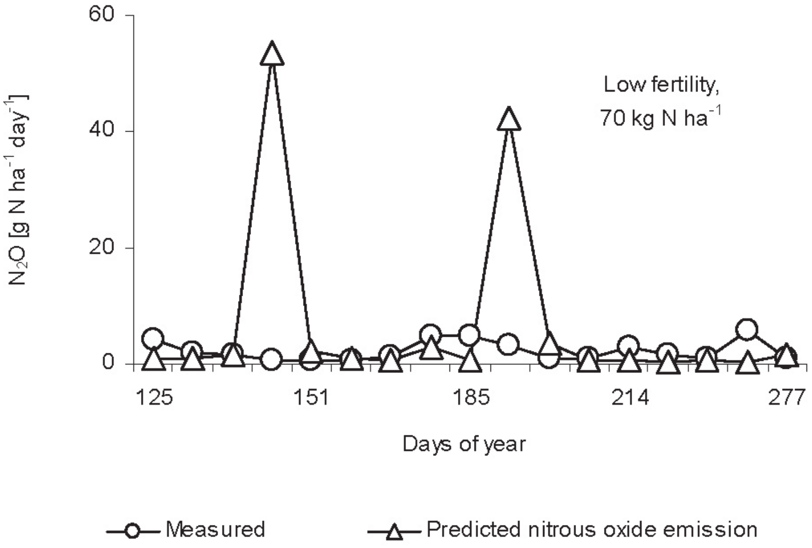


Fig. 6. Dynamics of the measured and predicted N_2O fluxes from loamy sand Spodosol under white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) in 2006 at the Menkovo experimental station (Russia)

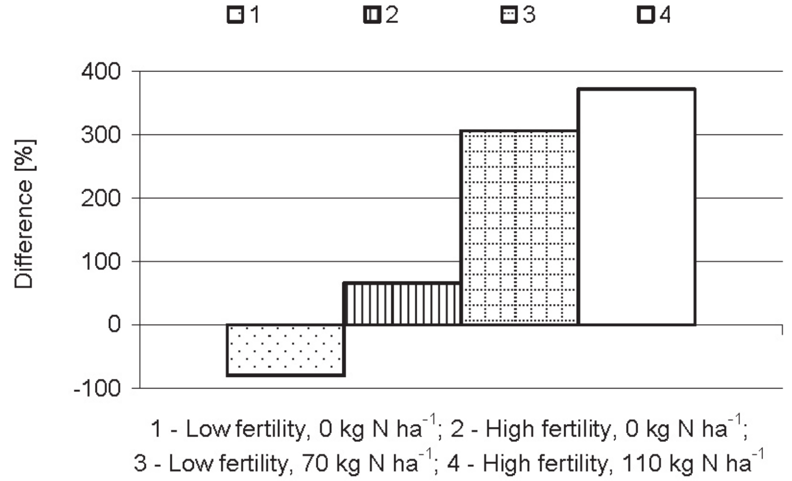


Fig. 7. Differences between the modeled and measured N_2O cumulative fluxes from loamy sand Spodosol with low and high fertility under white head cabbage (*Brassica oleracea* var. *capitata* f. *alba* L.) at the Menkovo experimental station in 2006 (Russia)

There were observed high negative differences between the modeled N_2O cumulative fluxes from the sandy loam Cambisol (Slovakia) and loamy sand Spodosol (Russia) with sugar beet and potato (–78 to –84%) as well as with spring barley (as shown in Fig. 8). The differences in precipitation and soil moisture content could result in the observed discrepancies in the modeled data for the selected sites in both countries.

The amount of precipitation in the Danubian Lowland was less than that in the NW Russia (Fig. 1). Therefore, the DNDC model was able to adequately predict the lesser N_2O cumulative fluxes resulted from a lower amount of precipitation and soil water in the soils in the Danubian Lowland.

Conclusions

Our results showed that the direct N_2O emission adequately responded to changes in precipitation, water-filled pore space and mineral N content during the growing seasons of spring barley, potato and white head cabbage on the loamy sand Spodosol. The results of comparison of the modeled against field observations demonstrated a distinguished capacity of the DNDC in

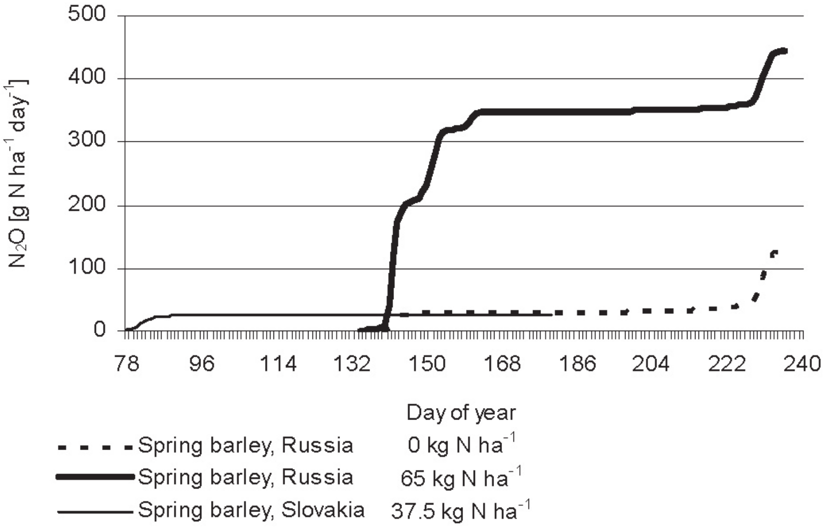


Fig. 8. Dynamics of the predicted N_2O cumulative fluxes from the loamy sand Spodosol and sandy loam Cambisol under spring barley (*Hordeum vulgare* L.)

predicting seasonal dynamics of the N_2O fluxes from this soil in selected treatments. The data on comparison tests of the modeled N_2O cumulative fluxes showed a satisfactory reliability of the DNDC model in the prediction of their seasonal dynamics in the selected agricultural sites of Slovakia and Russia.

Acknowledgement

A scholarship of the Ministry of Education of the Slovak Republic and the Slovak Academic Information Agency (SAIA) enabled Dr. E. Balashov to carry out 3-month studies at the Slovak University of Agriculture in Nitra. The study was made also with support of the grant project VEGA 1/0866/10 "Proposal of adaptive measures to reduce negative climate change impacts on agricultural landscape of Danubian lowland".

References

Buchkina, N.P., Balashov, E.V., Rizhiya, E.Y., Smith, K.A. 2006. Nitrous oxide emissions from a light agricultural soil of Northwestern Russia in relation to applied N fertilizer and manure. In Horn, R. (ed.). *Sustainability – its impact on soil management and environment. E-Proceedings of the 17th Triennal ISTRO conference held in Kiel, German, 28. August – 3. September, 2006*. Kiel: Christian-Albrechts-University, p. 1184.

Dobbie, K.E, McTaggart, I. P., Smith, K.A. 1999. Nitrous oxide emission from intensive agricultural systems: Variation between crops and seasons, key driving variables, and mean emission factors. *J. Geophys. Res.*, 104: 26891–26899.

Horák, J., Šiška, B. 2006. Evaluation of N_2O emissions by DNDC model from sandy loam soils of Danubian Lowland. *J. Envir. Engng Landsc. Mgmt,* XIV: 165–171.

Li, C., Frolking, S., Frolking, T.A. 1992. A model of nitrous oxide evolution from soil driven by rainfall events: Model structure and sensitivity. *J. Geophys. Res.*, 97 (D9): 9759–9776.

Li, C. 2000. Modelling trace gas emissions from agricultural ecosystems. *Nutr. Cycl. Agroecosyst.*, 58: 259–276.

Mosier, A.R. 2001. Exchange of gaseous nitrogen compounds between agricultural systems and the atmosphere. *Pl. Soil*, 228: 17–27.

Smith, K.A., McTaggart, I.P., Dobbie, K.E., Conen, F. 1998. Emissions of N_2O from Scottish agricultural soils, as a function of fertilizer N. *Nutr. Cycl. Agroecosyst.*, 52: 123–130.

Toky N_2O z poľnohospodársky využívaných pôd na Slovensku a v Rusku – priame merania a prognóza využitím modelu DNDC

Súhrn

Priame merania emisií N_2O sa uskutočnili pod porastami jačmeňa siateho (*Hordeum vulgare* L.), zemiakov (*Solanum tuberosum* L.) a hlávkovej kapusty (*Brassica oleracea* var. *capitata* f. *alba* L.) na hlinito-piesočnatých pôdach – spodosoliach v Rusku vo vegetačných obdobiach 2004 a 2006. Meranie emisií N_2O z pôdy sa uskutočnilo metódou uzavretej komory. Predikcia emisií N_2O z poľnohospodárskych pôd na Slovensku (Podunajská nížina) a severovýchodnej oblasti Ruska bola stanovená pomocou modelu DNDC. Porovnaním modelových a meraných emisií na pôdach v severozápadnom Rusku sa zistilo, že model je citlivý na zrážky, vyplnenie pôdnych pórov vodou a úrovne hnojenia vo vzťahu k tokom N_2O z pôdy. Porovnanie celkových tokov N_2O modelovaných pre pôdy Ruska a Slovenska ukázali, že model DNDC je možné použiť pre predikciu sezónnej dynamiky na vybraných poľnohospodárskych plochách.

Received January 18, 2010
Accepted April 12, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

The changes in the values of ecological-stabilization functional potentials of forests in the model area Český les

Jitka Fialová, Ilja Vyskot

Department of Landscape Management, Faculty of Forestry and Wood Technology, Mendel University in Brno,
Zemědělská 3, 613 00 Brno, Czech Republic, E-mail: jitka.fialova@mendelu.cz, vyskot@mendelu.cz

Abstract

Fialová, J., Vyskot, I. 2010. The changes in the values of ecological-stabilization functional potentials of forests in the model area Český les. *Folia oecol.*, 37: 16–22.

The aim of the work was to quantify the ecological-stabilization forest function by the method of Vyskot et al. (2003). The importance of living forests for sustainable development was discussed on many ministerial conferences. If we preserve forests, we will preserve life. Our study was pursued in a model area – a part of the protected landscape area Český les. The objective was to evaluate the real potentials of ecological-stabilization forest function and to see how these potentials are distributed in the individual forest management intervals. According to these results, we can discuss the previous management in the area. Both nature conservation and forest function needs require the quantification in both aspects. For the zones with declared protection, the needs of nature conservation have been defined, but the forest functions-related ones have not been included. The map of the distribution of real potentials for evolving ecological-stabilization forest function has been created.

Key words

declared zones of the nature conservation, forest management interval, forest stands, protected landscape area

Introduction

The purpose of our work was to analyse the nature protection needs and the society needs in forests ecosystems. Forests are a crucially important part of the environment. A considerable part of Czech forests is situated in protected areas. These areas are specified by the act Nr. 114/1992 Col., about the landscape and nature conservation. The whole forested area in the existing protected areas makes about 26.5% of the whole forested area in the Czech Republic. The research was carried out in the model area, within the Český les protected landscape area. The basic question were: which forest management intervals (20 years long periods) have the highest potential values for evolving ecological-stabilization forest functions and in what a way the forest management in last years can be discussed. The forest function potentials were evaluated for every forest stand of this type. The real potential of forest functions is quantified as the functional potential of forests (values of production functions) under optimum ecosystem conditions. The forest functions are controlled by effects of natural and ecosystem processes occurring in the forests.

Despite many centuries of human influence on forests, they have remained one of the best preserved components of nature and landscape, and as such, they are worth of corresponding attention within nature conservation. The forests covering one third of the Czech Republic area represent a considerable natural environmental potential for the landscape. If they are in the condition close to natural, they only need a minimum additional energy input. This holds even for forests managed for a rather long time. The necessity to preserve forests less affected by forest management, especially forests with their species composition close to the natural and forests with prevailing non-timber functions was responded by declaring the specially protected areas. The intensity of nature conservation significantly varies across these areas. The most of the surface is covered by third-zone forests for which general growing principles for commercial forests are usually sufficient. As for the existing nature conservation law, all forests, as an important landscape element, have granted with a general protection, however, without any special requirements on forest praxis.

As for the provisions of the nature and landscape conservation law, it is forbidden to manage national parks, 1st and 2nd zones of protected landscape areas, national natural reserves and natural reserves in a way requiring intensive technologies, especially means and activities that could cause considerable changes in the eco-system biodiversity, composition and function, or irreversible damage to the soil cover – as using biocides, changing water regime or carrying out extensive landscaping. The society admits that forests are special belongings supplying a number of additional benefits – apart from wood production; on the other hand, forest owners get no compensation for providing these functions. Decision on leaving the forests to their spontaneous development must be a part of a long-term elaborated preservation management strategy and must also be executed with respect to the forest crop pattern and the protected area category. It should not be a creditable or appreciated decision but a coherent part of complex approach to the management of protected forest areas. Important tools given to the nature conservation authorities by the nature and landscape conservation legislation are Conservation Plans. It is important that drafts of these Conservation Plans must be negotiated with forest owners and administrators, thus providing space for communication and seeking for mutually viable solutions. Differentiated conservation of forest eco-systems in various categories of specially protected areas is specified upon the Conservation Plans. As mentioned earlier, the tools for differentiated use of national parks and protected landscape areas are zoning and Conservation Plans. Zoning is the essential background for Conservation Plan design. Goals of nature preservation are formulated in long-term, medium-term and short-term time horizons. Long-term goals correspond with the cycles usual in forest management (rotation period, physical age of the crop). Current forest management must shift the existing forest management towards to the nature-close ensuring more ecological stability and fulfilling all requested forest functions. Goals and ways are to define transparently and easy to understand. The present public order of forest conservation needs to include not only the requirements on production of an ecologically valuable source – wood mass, but also equally strong requirements on preservation and recovery of natural environment with natural bio-diversity, contribution to soil conservation, well-balanced water regime, fixing of CO_2 and providing recreational possibilities in aesthetically pleasing natural environment (PELC and MOUCHA, 2008).

These requirements can only be defined upon the knowledge of authentic abilities of forest eco-systems in optimally possible eco-system conditions, i.e. with the knowledge of the real forest function potential and the value of total real potential of forest functions.

Many institutions, organisations and specialists advice of the need in evaluation and integration of forest functions to forest planning. They often refer to the revolutionary conferences and summits which progressively defined basic limits and principles. As an example we can mention BRIALES's approach (2003): "Integration of various functions into forest management can be evaluated whenever applicable indicators are available. These indicators must be applied to each forest unit and should be based on the resolution of the ministry conference concerning forest protection having taken place in Lisbon 1998. The indicators are homogenously combined into criteria. They can be applied in two possible ways: market possibilities with the aim to minimise expenses within sustainable development and the possibility of public incentives e.g. with the aim to create substitution products or benefits". Forest functions are naturally connected with the sustainable development (management) principle as proved by e.g. another research concentrating on multi-functional management of mountain forests: "Sustainable Forest Management and Certification" or "Multifunctional Mountain Forest Management" within the LIFE project (POLLINI and TOSI, 2000). It results in adaptation of traditional forest management with the aim of technical development, improved cost effectiveness and respecting of typical forest crop composition and sustainability of forests fulfilling e.g. protective, production and recreation functions. However, sustainability of forest management with multi-functional goals has to be defined upon continual assessment of a number of indicators.

OLENDEREK et al. (1995) mention the possibilities and advantages of forest monitoring systems for the purpose of multi-functional forest management. They developed the system and conception which projects especially the principle and attitude to the forest multi-functionality that are beneficial. The project is dedicated to the development and information support of the system of use and tools of multi-functional forest management. Presently, forests are a place where many conflict situations arise. Those are for example the conflicts between the principles of forest use and the needs of forest protection and sustainable forest management.

It is also important that the sustainable development should provide the important functions (protective, economical and social) both today and in future on local, regional and global levels without causing a threat to other eco-systems (Mośnil, 1994 in Olen-derek et al., 1995).

However, some authors such as Rykowski (1994) admit that evaluation of forest functions (abilities to fulfil forest functions) and their monitoring are very difficult. They agree on the need to separately quantify the functions and to set multiple criteria evaluation principles. They use the generally applied criteria and adapt the approaches for the conditions of Poland.

Olenderek et al. (1995) summarise partial conclusions and outcomes of their long-term research as follows: "Modern forestry must keep in mind the future and should therefore accept the need of stable forest existence. Multifunctional forestry was based on results and experience of many generations of foresters. However, new theories, tools and applications should be used more extensively at present. Complex monitoring and forest evaluation is one of these tools".

Material and methods

For the evaluation of forest function real potentials in the model area, the ecosystem method Vyskot et al. (2003) was chosen. The so called all-society forest functions are evaluated in the ecosystem units with the interaction with the forest partition (Vyskot et al., 2003). This method evaluates 6 groups of forest functions: bioproduction, ecological-stabilization, edaphic-soil conservation, hydric-water management, sanitary-hygienic and social-recreational forest functions (Fig. 1). In this work the ecological-stabilization forest function was evaluated. Natural and implemented all-society functions of forests are determined by synergetic effects of the spectrum of elements and segments of a forest ecosystem. Ecosystem functional parameters of the ecosystem elements and segments or their interacted or additive aggregations form determination criteria of functions. They are divided according to the type of source and processing as follows:

Direct parameters are documented in data and overviews of the forest management plans database of the CR forests (characterizing particular defined forest units). Indirect parameters are documented by other database sources (different hierarchical level of site and application units).

Ecological-stabilization potential is quantified as the maximum possible functional capacity of forest ecosystems (value of the production function) necessary for maintaining balance in energo-material flows under optimum ecosystem conditions, and controlling self-regulation processes and resistance to disturbances. Real species composition is the direct criterion for the ecological-stabilization forest function. With increasing species diversity, ecological stability of the stand also increases. Natural communities showing high ecological stability despite low biodiversity are an exception. A rich species composition enables more interactions among the ecosystem functions. Monocultures and more or less pure types are more prone to damage by abiotic and biotic agents.

Degree of naturalness of a stand type – as an indirect criterion expresses to what extent the real species composition corresponds to the site conditions. With the increasing degree of naturalness, the self-regulation potential of the stand is improved as well as its resistance to stress factors. The degree of the stand type naturalness is determined through the relationship of the real species composition to the natural species composition corresponding to the real natural conditions (Table 1).

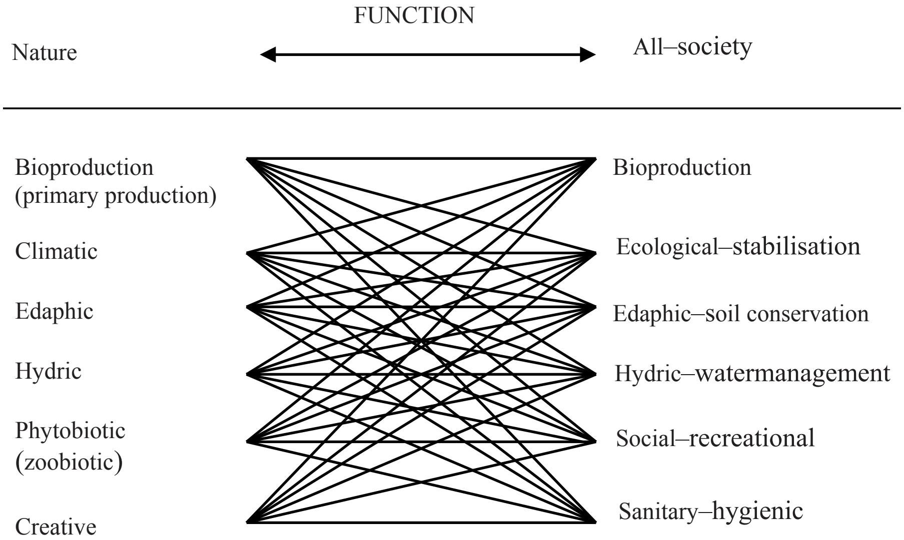


Fig. 1. Effectiveness groups of all-society functions of forests on the basis of ecosystem function synergies (Vyskot et al., 2003)

The data we used for the quantitative evaluation non-wood benefits forest function were taken from forest management plans. In the Czech Republic, forest management plans are designed at 10-year intervals. For our purposes we needed the data on the stand type and functional target management group.

For ecological-stabilization forest function is also important the stand age. Stand types are species schemes created according to the proportion of the particulate species in the stand composition. Functional target management group specifies related higher practical units of forest ecosystem types of the real species composition characterized by limits on natural conditions.

Value classification of real potentials of forest functions goes from 0 (functional unsuitable) to 6 (extraordinary).

The map of the real potentials patterns of ecological-stabilization forest function was created in the ArcGIS 9.2. In this software the data analysis was processed. By the database task were the stands assorted according to the age of forests into the proper interval. The length of the forest management interval is 20

Table 1. Example of the real potentials value degree for 3 chosen forest functions (Vyskot et al., 2003)

45	BP	ES			HV						
Stand type	RP Ø	Species diversity	Natural composition	RP Ø	Horizontal precipitation	Potential infiltration	Potential runoff	Interception	Evapotranspiration	Soil permeability	RP Ø
C1	5	0	1	1	0	0	0	2	1	4	2
D1	5	1	2	2	0	0	0	2	1	4	2
M1P3	4	2	3	3	0	0	0	2	1	4	2
D1P3	4	1	2	2	0	0	0	2	1	4	2
C6	5	0	5	3	0	2	0	4	0	4	2
M1P5	5	2	3	3	0	0	0	2	1	4	2

45, functional target management group; BP, bioproduction forest function; ES, ecological-stabilisation forest function; HV, hydric-watermanagement forest function; C1, pure spruce stand type; D6, mixed stand type with the „dominant" proportion of beech; M1P3, mixed stand type of spruce and admixed pine; D1P3, mixed stand type with the dominant proportion of spruce and admixed pine; C6, pure beech stand type; M1P5, mixed stand type of spruce and admixed oak; RP Ø, average value of real potential.

Value degrees of real potentials: 0 – functionally unsuitable, 1 – very low, 2 – low, 3 – average, 4 – high, 5 – very high, 6 – extraordinary.

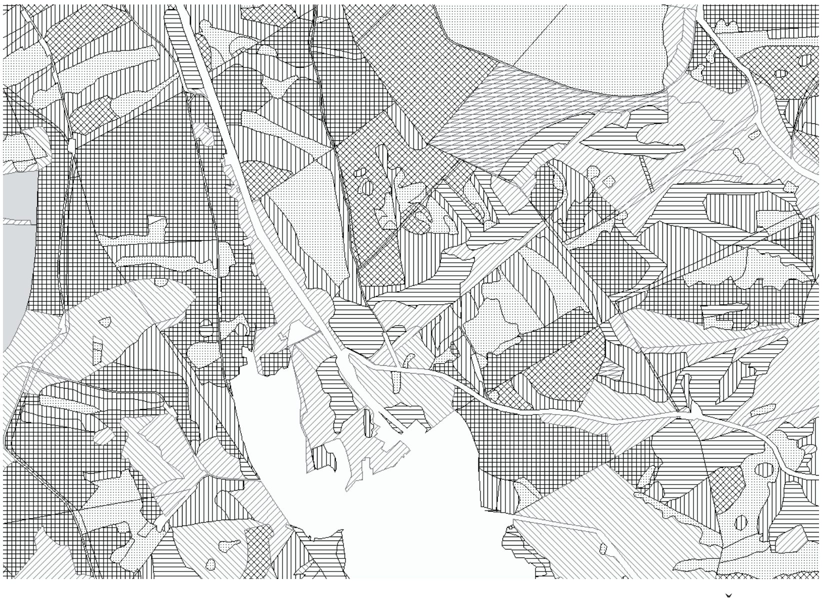


Fig. 2. The map print of the time management interval on the model area Český les

I. 1 – 20 ░ II. 21– 40 ▥ III. 41 – 60 ▤ IV. 61 – 80 ▨ V. 81 – 100 ▧ VI. 101 – 120 ▦
VII. 121 – 140 ▩ VIII. 141 – 160 ▨ IX. 161 – 180 □ X. 181 – 200 ■

years (intervals 1–20, 21–40, 41–60 etc., Fig. 2). After this analysis we analysed the distribution of the ecological-stabilization forest function potentials in the forest management interval. The extent of the unit classification of potentials in different forest management interval was found out and the percentage representation. On the basis of these results we are able to discuss the previous forest management. How the values of the ecological-stabilization forest function were projected in the forest management plans and how the harvesting was focused.

Results and discussion

There were analysed 662.4 ha of forests in the Český les. The values of real potentials of ecological-stabilization forest function were quantified and the surface and percentage distribution of forest in the real potential values classes was established.

For the quantitative evaluation of forest´s point of view, the maps made in GIS have the most important predicative worth. In the Fig. 3, one can see the distribution of real potential values (ecological-stabilization forest function).

The results of evaluation were analyzed, and the distribution of the highest value of real potentials in the age classes (20 years period) was determined. The results of this analysis are shown in the Table 2.

The highest achieved value of the real potential of ecological-stabilization potential of forest function is 5, so the very high. The highest percentage surface cover of the very high ecological-stabilization potential of forest function is in the I. and in the VII. forest management interval. The ecological ecosystem approach in the last twenty years has been projected in this very high real potential of ecological-stabilization forest function and that the management was influenced, and still is, by this approach. Very interesting results were obtained in the IX. forest management interval. The achieved value of ecological-stabilization potential of forest function is 1 (very low), and the stands with this value in IX. forest management interval cover 100%.

The positive result is that some parts of stands in the I., II., III., IV., V. and VII. forest management interval have attained the very high ecological-stabilization potential of forest function (value 5). The needs of nature conservation are defined in the forest management plan, but the forest functions are not included in the declaration procedure. For the comparison of ecological-stabilization forest function real potentials distribution and declared zones of nature conservation distribution the Fig. 4 is enclosed.

For the synergy of nature conservation and forest function need`s detection is it necessary to quantify both of them. It was necessary to interconnect known aspects of the nature conservation (projected in the zonation) with the forest function quantification. The suggestion whether the nature conservation needs are in the conjuction with the high functional potentials of forests was very important. If we compare the map of declared zones of the nature conservation and the map of the real potentials of ecological-stabilisation forest function, the results is that the contemporary zonation is really one-sided and does not respect the parallel side-run of the nature conservation needs and forest function needs.

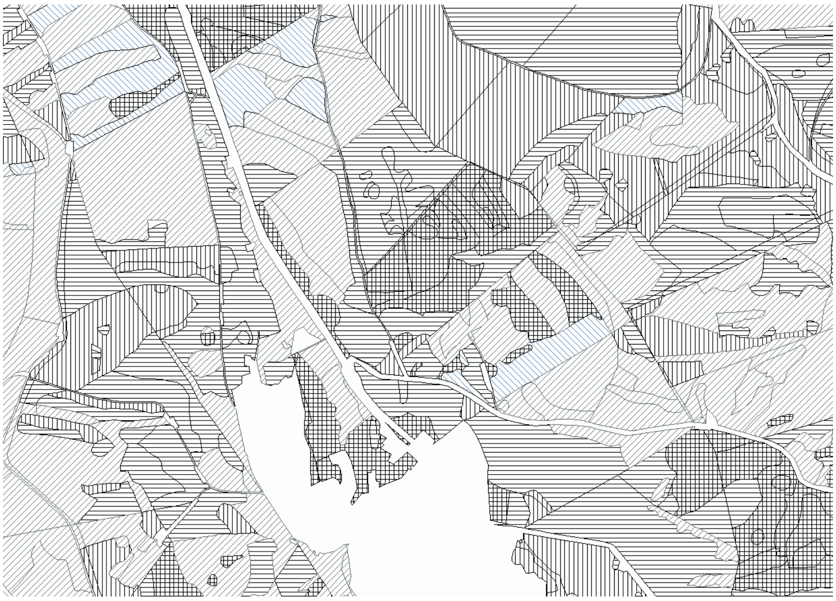


Fig. 3. The map print of real potential of ecological-stabilization forest function on the model area Český les
Value degree 0 ░ Value degree 1 ▥ Value degree 2 ▤ Value degree 3 ▨
Value degree 4 ▧ Value degree 5 ▦ Value degree 6 ▩

These results do not follow the ideas of Briales (2003), Olendrek et al. (1995) or Rykowski (1994). We should implement these ideas in the law of the Czech Republic, not only in the forest law but in the nature protection law as well.

Conclusion

The area of 662.4 ha was analyzed and the real potentials of ecological-stabilization forest function were found out. A GIS distribution map was created and the analysis of the highest real potential in the age classes was made. We can say that the ecological ecosystem approach in the last twenty years has been projected in a very high real potential of ecological-stabilization forest function and that the management was influenced and still is, by this approach.

Acknowledgement

The study has been supported by Research plan of the Faculty of Forestry and Wood Technology Mendel University in Brno – MSM 6215648902 and the project VaV Sp-2d3-56-07 „Ecological and economic evaluation of social functions of alternatively structural forests“.

Table 2. The distribution of the highest value of ecological-stabilization real potentials in the management time interval (interval of forest age)

Management time interval	Area of the management time interval in ha	The highest value of ecological-stabilisation real potential	Part of surface with the highest value of real potential in the management time interval [%]
I. (age 1–20)	341.4	5	18
II. (age 21–40)	6.3	5	6
III. (age 41–60)	34.8	5	2
IV. (age 61–80)	31.1	5	9
V. (age 81–100)	121.5	5	2
VI. (age 101–120)	12.4	3	67
VII. (age 121–140)	69.9	5	25
VIII. (age 141–160)	17.7	4	19
IX. (age 161–180)	9.4	1	100
X. (age 181–200)	17.9	3	46

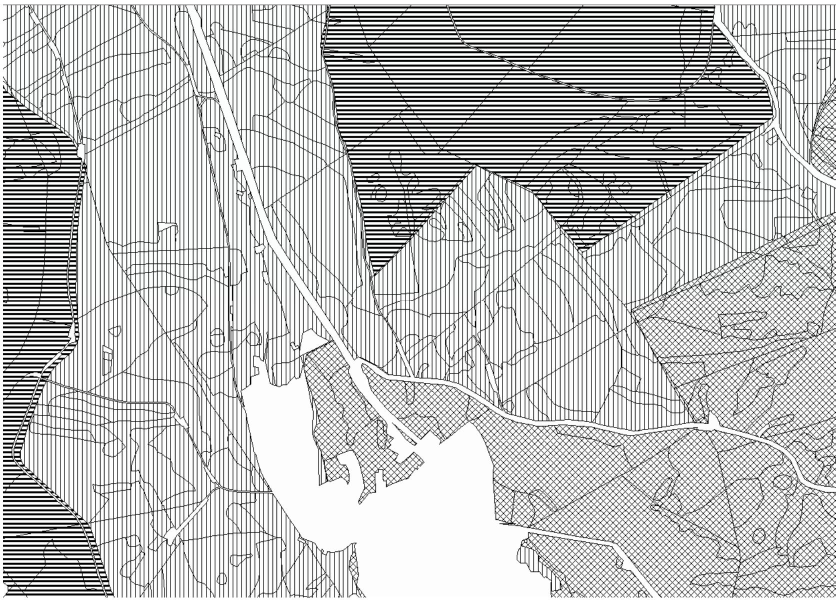


Fig. 4. The map print of the declared zones of the nature conservation (Český les protected landscape area)

1st zone ▥ 2nd zone ▤ 3rd zone ▦

References

BRIALES, E.R. 2003. Forest management planning as an instrument for monitoring, optimising and incentivating sustainable forest management. In BRUN, F. (ed.). *The formulation of integrated management plans (IMPs) for mountain forests. Proceedings of the International Research Course, Bardonecchia, Italy, 30 June – 5 July 2002*. Grugliasco: Dipartimento di Economia e Ingegneria Agraria, Forestale e Ambientale, p. 55–62.

OLENDEREK, H., MOZGAWA, J., BEDKOWSKI, K., KORPETTA, D., NOWICKI, A. 1995. *Forest Monitoring System for Multifunctional Forestry*. Warsaw: Warsaw Agricultural University [cit. 2003-13-05]. <http://witch.sggv.waw.pl/fms1283>

PELC, J., MOUCHA, P. 2008. Současné lesnictví a ochrana přírody [Current forestry and nature conservation]. In *Ochr. Přír.*, 63, Lesy a ochrana přírody monotematické číslo: 5–7 [cit. 2008-07-03]. <http://www.ochranaprirody.cz/res/data/144/019231.pdf>

POLLINI, C., TOSI, V. 2000. Multifunctional management in the Alpine mountain forests. In XXI IUFRO World Congress, K. Lumpur, 2000. *Group Session TF2 "Forests in Sustainable Mountain Development"*. [cit. 2003-12-05]. <http://www.isafa.it/scientifica/gestione-sostenibile/gestione-sostenibile.htm#e>

RYKOWSKI, K. 1994. Program badawczy – Modele leśnictwa wielofunkcyjnego.[Research project „A model of multi-objective forestry“]. In *Polska polityka kompleksowej ochrony zasobów leśnych*. Warszawa: MOSZNIL.

VYSKOT, I. 2003. *Quantification and Evaluation of Forest Functions on the Example of the Czech Republic*. Prague: Ministry of Environment of the Czech Republic. 218 p.

Změny v hodnotách reálných potenciálů ekologicko-stabilizační funkce lesů na příkladu modelového území Český les

Souhrn

Cílem práce bylo kvantifikovat ekologicko-stabilizační funkci lesů metodou VYSKOT a kol. (2003). Na mnohých ministerských konferencích o lesích byla diskutována důležitost živých lesů pro udržitelný rozvoj společnosti. Pokud budeme pečovat o lesy udržitelným způsobem, můžeme zajistit i trvalý život na Zemi. Pro práci bylo vybráno modelové území, kterým je nejjižnější část CHKO Český les. Cílem práce bylo nejen hodnocení funkcí lesů, ale také zjištění, jak jsou hodnoty reálných potenciálů distribuovány v rámci stanovených časových intervalů managementu (délka intervalu je 20 let). V závislosti na těchto výsledcích můžeme diskutovat předchozí management uplatňovaný v území a přístup společnosti k ochraně životodárných lesů. Bylo analyzováno území o rozloze 662,4 ha a vyhodnoceny reálné potenciály ekologicko-stabilizační funkce lesů. V prostředí GIS byla vyhotovena mapa distribuce hodnot reálných potenciálů této funkce a pomocí databázových dotazů byla provedena analýza zastoupení jednotlivých hodnot reálných potenciálů v časových intervalech managementu. Můžeme na základě výsledků říci, že ekologický ekosystémový přístup k životnímu prostředí uplatňovaný v posledních dvaceti letech je promítnut do vysokých hodnot reálných potenciálů ekologicko-stabilizační funkce lesů a že management byl velmi ovlivněn a stale tímto přístupem pozitivně ovlivněn je. Práce je podložena hodnocením pomocí objektivní ekosystémové metody uznané Ministerstvem životního prostředí ČR. Porovnání reálných účinků lesů, tedy reálných funkčních potenciálů lesů, se stavem porostů na území CHKO je v současnosti jedinou prací, která se touto problematikou zabývá.

Received December 14, 2009
Accepted June 3, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Soil water availability in a short rotation poplar coppice (*Populus nigra* × *P. maximowiczii*) in Czech-Moravian Highlands

Milan Fischer[1], Miroslav Trnka[1], Jiří Kučera[2], Zdeněk Žalud[1]

[1]Institute of Agriculture Systems and Bioclimatology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
[2]Environmental Measuring Systems, Turistická 5, 621 00 Brno, Czech Republic
[1]E-mail: fischer.milan@gmail.com, mirek_trnka@yahoo.com, zalud@mendelu.cz
[2]E-mail: jiri.kucera@emsbrno.cz

Abstract

Fischer, M., Trnka, M., Kučera, J., Žalud, Z. 2010. Soil water availability in a short rotation poplar coppice (*Populus nigra* × *P. maximowiczii*) in Czech-Moravian Highlands. *Folia oecol*., 37: 23–34.

There are presented results of a study of soil moisture dynamics, its spatial patterns and soil water availability under poplar coppice (*Populus nigra* × *P. maximowiczii*). The study took place in a short rotation poplar coppice culture (SRC) situated in the locality Domanínek (the Czech Republic, 49°32' N, 16°15' E, 530 m a.s.l.). Generally, the soil water content increased with the depth throughout the whole soil profile 0–0.95 m. The driest period occurred towards the end of summer, within an almost one month-long period without any precipitation. In this time, also the highest spatial variability was recorded. The water content in soil profile reached its highest value, and the spatial variability was the lowest, at the beginning of spring after the snow had melted and also after prolonged rainfall episodes during summer. The response of poplars to the water stress was analysed, and it was noted that the growth starts to be significantly limited at half of the range between the field capacity and the wilting point. The goal of the overall study is to identify correlations between the biomass increment rates and meteorological, planting and ecological factors to allow for better selection of SRC growing areas and more precise yield predictions.

Key words

short rotation coppice, soil moisture spatial and temporal patterns, water availability

Introduction

Short rotation coppice (SRC) has recently received increased attention as a renewable source of biomass for energy in the EU countries. The SRCs can become an important source of renewable energy – mainly due to their high biomass yields, good combustion quality (as solid fuel) and comparatively low biomass production costs (Kauter et al., 2003). In addition to its bioenergy potential, SRCs have many other ecological advantages – e.g. positive impacts on biodiversity (small mammals, birds, insects, etc.), nutrient capture, soil protection from wind and water erosion) and also better water management in ecosystems (Isebrands and Karnosky, 2001). More recently, the importance of plantation forestry as a greenhouse gas mitigation option, and the need to monitor, preserve, and enhance terrestrial carbon stocks have been recognized by the United Nations Framework Convention on Climate Change in the Kyoto protocol (Updegraff et al., 2004).

The largest areas of SRC (totally a few thousands of hectares) are situated in Scandinavia, Germany, UK, Italy, Belgium and France (Slatter et al., 2001; Kauter et al., 2003). The main reason why the plantations of SRC are not so widely-used is the economic situation, as there must compete with fossil fuels, other renewable energy sources, as well as residual biomass from the agriculture and wood-processing industry. Furthermore, in most cases, SRC is inferior under the given economic and political conditions (Kauter et al., 2003). One of the ways how to increase the SRC areas could be not only to offer recently supplied grants but also to optimize the technology of planting SRC on farmland. Selecting areas and establishing the SRC (in the case that the owner is going to put to use the grants) is ensured according to legislation in cooperation with accredited experts and in terms of the project (e.g. Weger and Havlíčková, 2003). The estimation of biomass production is subjective and mostly takes into account the genotype of the plant, while the role of meteorological, soil, phytopatological and herbological conditions at the given site is not fully appreciated. Therefore the use of production ecology methods that are based on mathematical modelling of growth and evolution of the plants seems to be a very promising approach. Such models which are based on exact measurements of the biotic processes and their linking with abiotic environment and subsequently formulated to general algorithms are very useful just for making decisions about where, how, and in some cases even which clones would be most suitable for planting. However using these tools requires a sufficient number of high-quality experimental data to calibrate and verify the models.

The responses of poplars and willows to drought may be the key constraint to productivity since their natural distribution and productivity are closely related to the seasonal availability of soil water (Braatne et al., 1992; Deckymn et al., 2004; Lindroth and Båth, 1999). For that reason the evaluation of soil moisture and its temporal and spatial patterns in poplars plantation is the main aim of this study. The results should contribute to a development of modelling schemes described above.

Material and methods

In April 2002, a high-density experimental field plantation for verification of the performance of poplar clone J-105 (*P. nigra* × *P. maximowiczii*) with the total area of 4 ha was established in Domanínek (Czech Republic, 49°32′ N, 16°15′ E and altitude 530 m a.s.l.). The plantation was established on agricultural land previously cropped predominantly for cereals and potatoes. Hardwood cuttings were planted in a double row design with inter-row distances of 2.6 m and spacing of 0.7 m within rows accommodating a density of 9,000 trees/ha. Soil conditions at the location are representative of the wider region with deep luvic Cambisol influenced by gleyic processes and with a limited amount of stones in the profile. The site itself is situated on a mild slope of 3° with an eastern aspect and is generally subject to cool and relatively wet temperate climate typical for this part of Central Europe with mingling continental and maritime influences. Although the area does not provide optimal conditions for SRC based on *Populus* sp. clones, the site itself is highly suitable for planting due to deep soil profile (Trnka et al., 2008).

In May 2007, an array of 16 access tubes was installed into the soil for portable datalogging with a PR1 profile probe (Delta-T Devices Ltd., UK) – a system measuring dielectric properties of soil, which are straight depending on soil water content. PR1 profile probe enable to evaluate volumetric content of soil water [%] in different depth (0.1, 0.2, 0.3 and 0.4 m). The layout of access tubes is designed to record differences in soil moisture between double rows and inter-rows and the soil moisture variability itself within the investigated area which is roughly 600 m^2 large. Readings were taken usually once a week. In July 2007, 2008 and 2009, soil sampling took place and the field capacity with the wilting point was determined together with other useful soil characteristics like bulk density, textural composition, etc.

In July 2008, 14 m high mast with system for measuring actual evapotranspiration by Bowen ratio (EMS Brno, Czech Republic) was placed in the centre of the poplar plantation. At the same place below ground, three sensors EC – 20 (Decagon Devices, USA) for measuring volumetric water content of soil and six gypsum blocks (EMS Brno) to measure soil water potential were accommodated in the depths 0.1 m, 0.3 m and 0.9 m. All sensors were connected to datalogger ModuLog 3029 (EMS Brno) and measuring step was adjusted to measure each 2 minutes and to store each 10 minutes. The three sensors EC – 20 and PR1 profile probe were calibrated through gravimetric method in order to increase measurement precision.

At the same time, the tipping bucket rain gauge MetOne 370 (MetOne Instruments, USA) was placed next to the poplar plantation.

Soil water availability was determined as an amount of soil water content [mm] up the level of wilting point. It was expressed for particular depths and summarise for soil profile. In the case of portable RR1 profile probe, the soil profile was 0.45 m deep and for the three permanent sensors was 0.95 m deep. The particular depths in the profile 0–0.95 which were not measured (namely 0.15–0.25, 0.35–0.45, 0.45–0.55, 0.55–0.65, 0.65–0.75 and 0.75–0.85), were simplified calculated using the weighted averages from the values of measured depths.

For estimating biomass increment and its reaction to soil water availability an array of 40 mechanic DB 20 and 3 automatic dendrometres DRL 26 (EMS Brno) were fixed to trunks at the breast height. These dendrometers are designed for long-term registration of tree trunk circumference via stainless tape that encircles the tree trunk. The values of increment of stem circumferences or diameters are very useful because they could be subsequently converted through the allometric equation to increment of biomass (e.g. Fajman et al., 2009). In this work we used the average values from the three automatic dendrometres and correlated them with the records of available soil water content measured by the three permanent buried sensors EC – 20.

Results

The course of mean soil water volumetric content during the seasons 2008 and 2009 is shown in Fig. 1. It is evident that the second of the observed years was the wetter one. There are two peaks in the dynamics of soil moisture during the year 2009. The first peak is linked to soil saturation with water after snow melting at the beginning of spring and the second one is associated with strong summer rainfall**.** On the other hand, the lowest values were recorded at the end of summer and first part of autumn in both monitored years.

The spatial soil moisture variability is expressed by using a standard deviation at the Fig. 2. It is obvious that values of the standard deviation decrease with the higher mean soil moisture and on the contrary during the drier period increase. This relationship is especially true for the three deeper soil layers. In the case of superficial layer (0–0.15 m), no significant linkage for the mean soil moisture and standard deviation is observed.

The relationship between the mean soil moisture within the plot and the standard deviation is depicted in Fig. 3 and numeric expression through the correlation coefficients is placed in Table 1. We can observe that the absolute variability, i.e. the standard deviation, increase almost linearly with decreasing soil moisture. Furthermore, Fig. 3 shows that this relationship is depth dependent, with important difference between the superficial depth (0–0.15 m) and more profound depths (0.15–0.45 m). We can also recognise here that the depths 0.2 and 0.4 m reach highest variability. On the contrary the depth 0.3 shows the lowest variability of soil moisture. Depletion in soil moisture together with

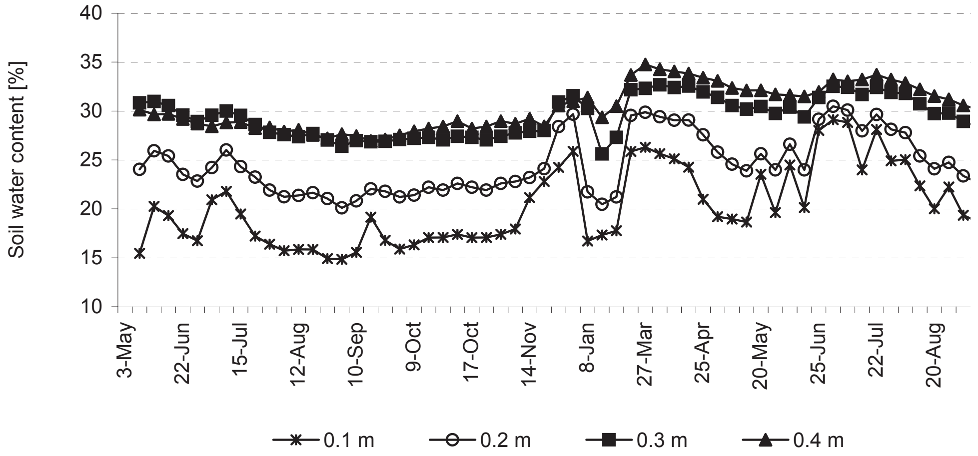


Fig. 1. Seasonal dynamics (2008–2009) of soil moisture in different depths (0.1–0.4 m) expressed in moisture volumetric percentage

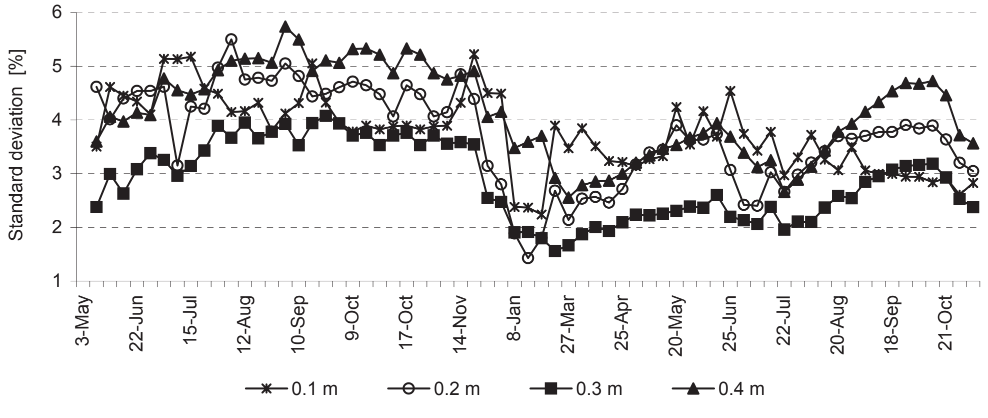


Fig. 2. Seasonal dynamics (2008–2009) of standard deviation of soil moisture in different depths (0.1–0.4 m) expressed in percent of volumetric soil moisture

standard deviation in the course of winter months (from December to March) was left out from the evaluation because it was induced by freezing of soil water, not by water deficit.

The spatial soil moisture variability is also well obvious at Figs. 4–7. The particular top views on investigated plot are created for each depth (0.1–0.4 m) and each figure depicts different date. The Fig. 4 shows spatial soil moisture variability in one day during the driest period in September 2008. We can observe here very wide range of soil moisture values in the depth 0.4 m. On the other hand, closer to the surface, especially in 0.1 m depth, the soil was very dry with no higher spatial differences.

The opposite situation of soil moisture dynamics depicts Fig. 5. At these top views, we can observe the soil moisture variability in our monitored plot during the early spring period after snow melting. In this case variability is the lowest in the depth 0.4 m and reaches higher values closer to the surface. We can also find resembling patterns of soil moisture variability in Fig. 6 which refers to the situation after summer rainfall.

Fig. 7 shows again the beginning of autumn where the soil profile usually reaches the lowest soil moisture content. These top views from September 2009 are quite similar to those which we observed in September 2008. Generally, the year 2008 was much drier, as we can see at the Fig. 1. It also confirms the top views from Fig. 4 and Fig. 7, which represent the driest moment of the two years of monitoring.

In plant production, the information about water availability has much higher value than other growth predictors. The Fig. 8 expresses the mean temporal dynamics of soil available water in whole profile (0–0.45 m). The standard deviation refers to the spatial variability of available water across the investigated plot. The maximal values of the mean available water throughout the whole profile ranged around 70 mm whereas the minimal values decreased to 30 mm.

As we can see also at Fig. 9, the minimal values of available water were measured understandably near the surface. The events of zero water availability were in few cases observed deeper from the surface. The relationship between mean soil water availability and the standard deviation (Fig. 9 and Table 2) is analogical to the relationship of mean soil moisture content and its standard deviation (Fig. 3). The only difference is distinctive in the superficial layer (0–0.15 m) where the correlation of mean values and standard deviation was positive (Table 2). The spatial variability of the soil water availability is also depicted on Fig. 10, where the particular days are chosen.

As we could see above, soil water availability in the soil profile 0–0.45 m ranged from the field capacity to the stress point and sometimes also a little bit lower. The reaction of poplars trees to lack of water which can be easily extracted by the root system is depicted at Fig. 11. There are clearly visible peaks in diurnal patterns of stem diameter increment, which are linked to the peaks of increased soil water availability. Naturally, these sudden increases of the soil water content refer to the

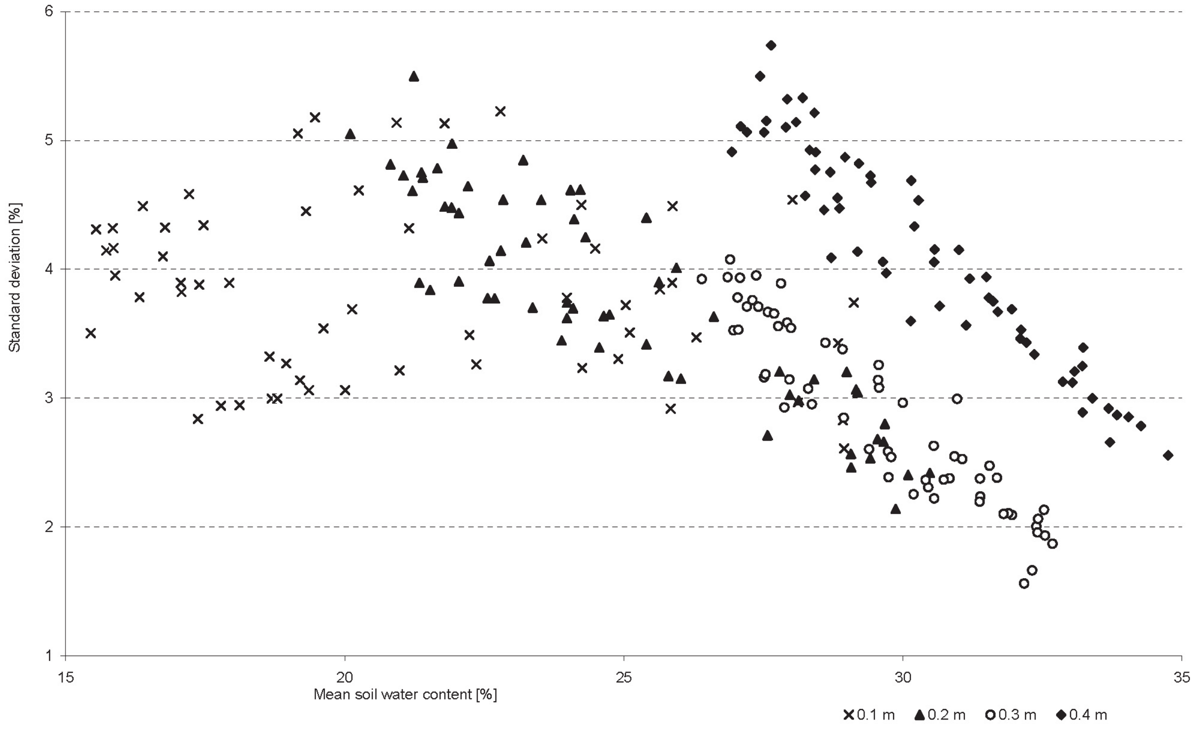


Fig. 3. Standard deviation of soil moisture [%] versus mean soil water volumetric content [%] in different depths

occurrence of precipitation. By omitting these short-term trunk swellings during the day with precipitation in further analyses we can observe that if the available water supply gets roughly around 30 mm, the diurnal rates of stem diameter increment significantly decrease. The relationship between content of available soil water within the whole soil profile (0–0.95 m) and the diurnal increment of stem in diameter is well illustrated at Fig. 12 and the same situation after omission the values from day with precipitation at Fig 13. The correlation coefficients for the particular layer over the whole profile are placed in Table 3.

Table 1. Correlation coefficients describing the relationship between the mean soil moisture content [%] and the standard deviation of soil moisture content [%] in different layers

Soil layer	Correlation coefficients
0–0.15 m	–0.192
0.15–0.25 m	–0.888
0.25–0.35 m	–0.936
0.35–0.45 m	–0.950

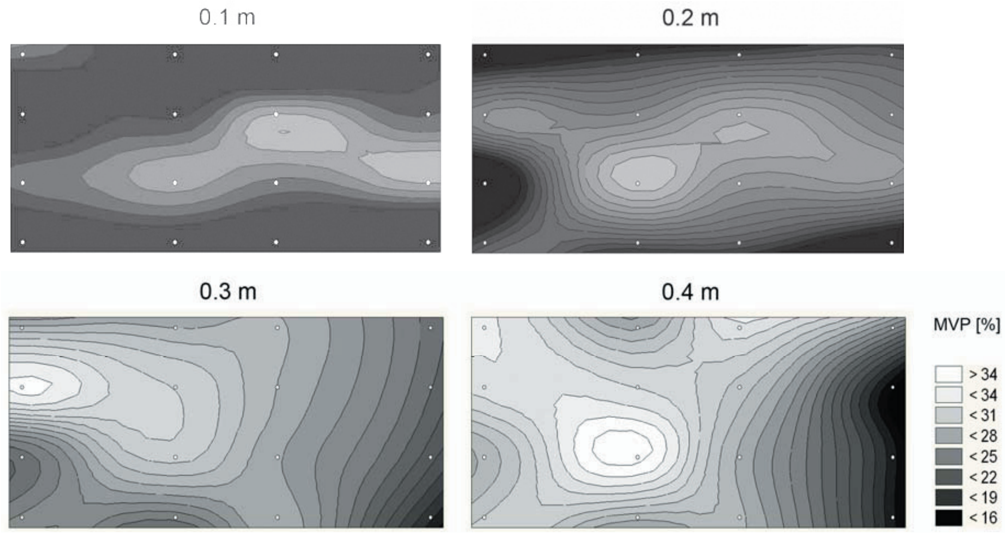


Fig. 4. Spatial patterns of soil moisture content in particular depths during the driest day (6/9/2008). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

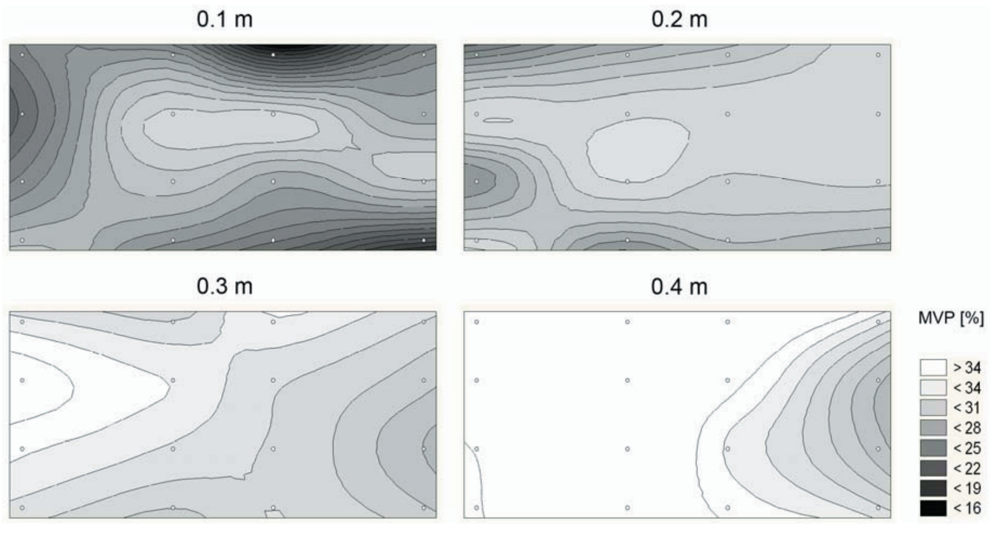


Fig. 5. Spatial patterns of soil moisture content in particular depths during the day after snow melting (27/3/2009). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

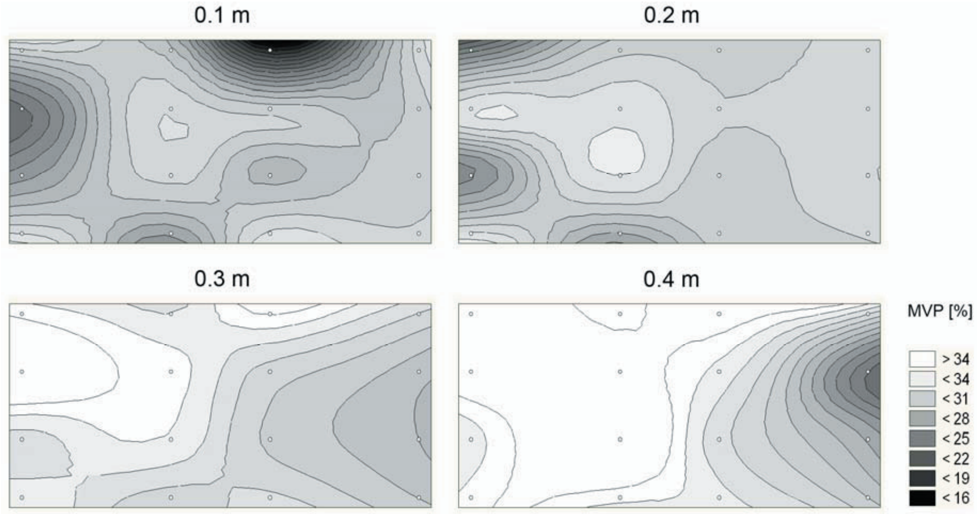


Fig. 6. Spatial patterns of soil moisture content in particular depths during the day after a strong rainfall (2/7/2009). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

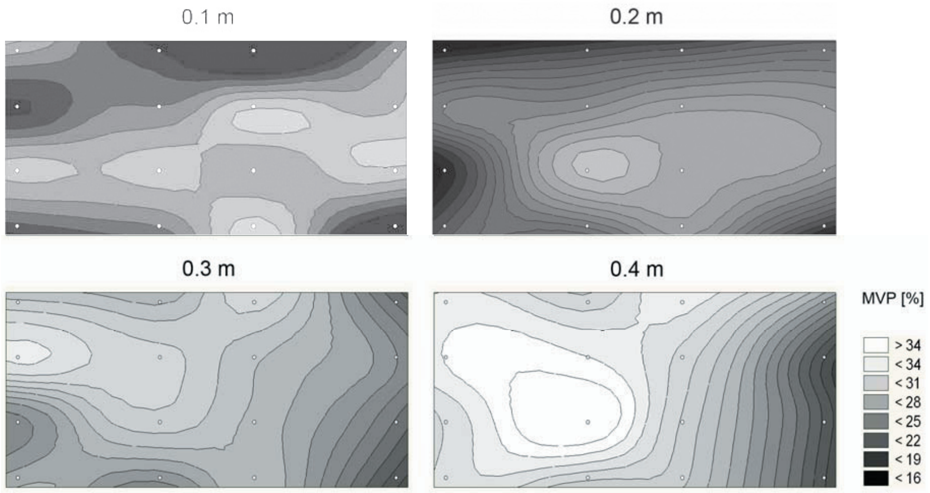


Fig. 7. Spatial patterns of soil moisture content in particular depths within another very dry day (23/9/2009). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

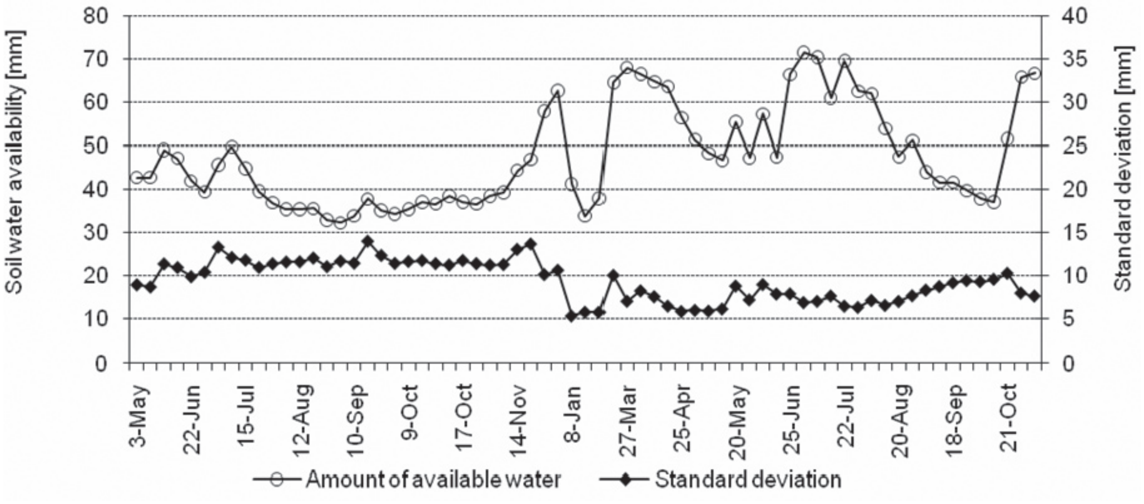


Fig. 8. Seasonal dynamics of average available soil water content in the profile 0–0.45 m measured for all 16 access tubes and its spatial variability expressed as the standard deviation (both in mm of available water)

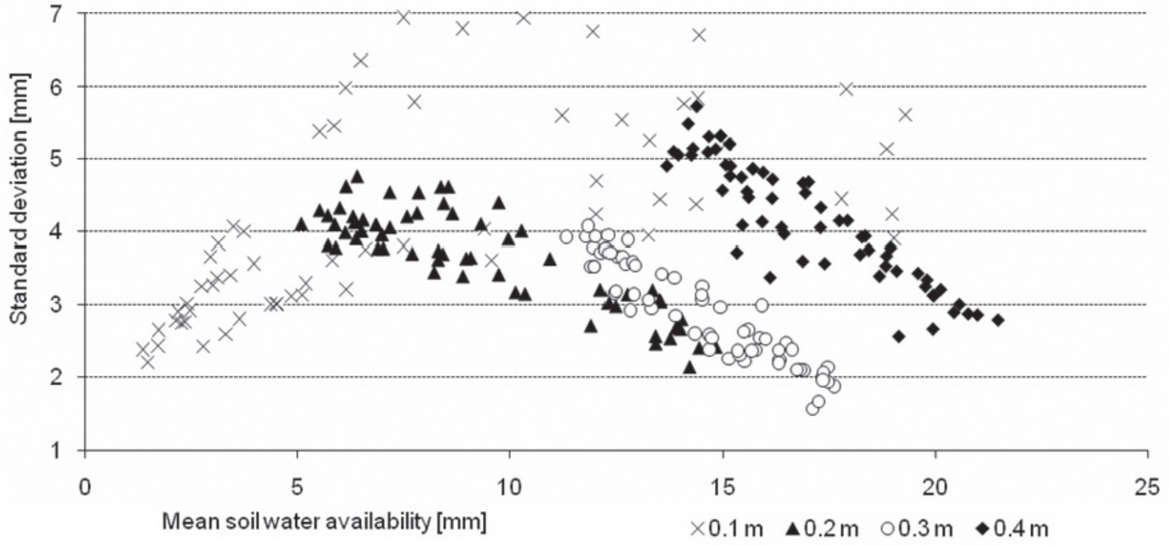


Fig. 9. Standard deviation of soil water availability [mm] versus mean available soil water content [mm] in different depths

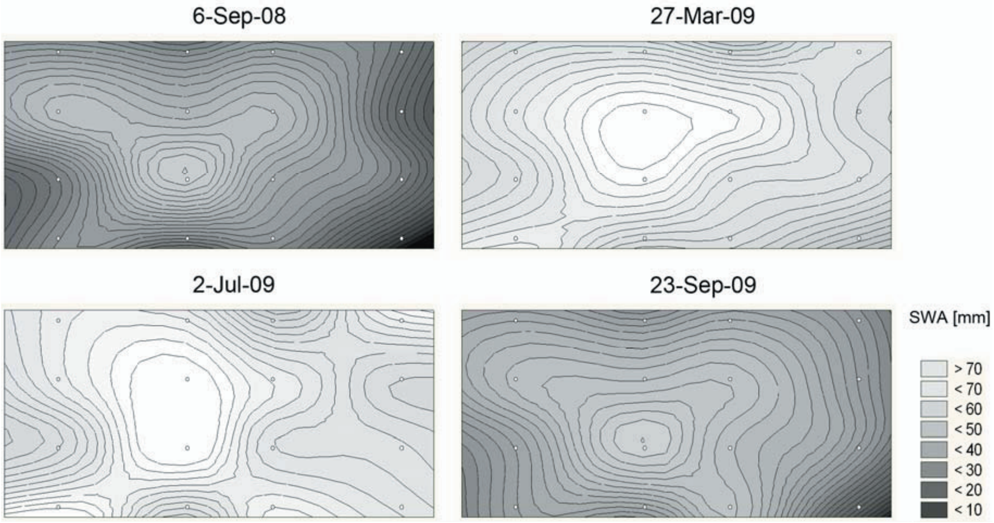


Fig. 10. Spatial patterns of soil water availability (SWA) in the whole profile 0–0.45. Each picture symbolizes a particular day. There are depicted two days when poplars suffered from water stress (6/9/2008 and 23/9/2009) and two days with sufficient available water (27/3/2009 and 2/7/2009). The scale from white to black depicts the range of soil moisture availability [mm] from the wettest to the driest areas.

Table 2. Correlation coefficients describing the relationship between the mean soil water availability [mm] and its standard deviation [mm] in different layers

Soil layer	Correlation coefficients
0–0.15 m	0.630
0.15– 0.25 m	–0.851
0.25– 0.35 m	–0.936
0.35–0.45 m	–0.933
0–0.45 m	–0.653

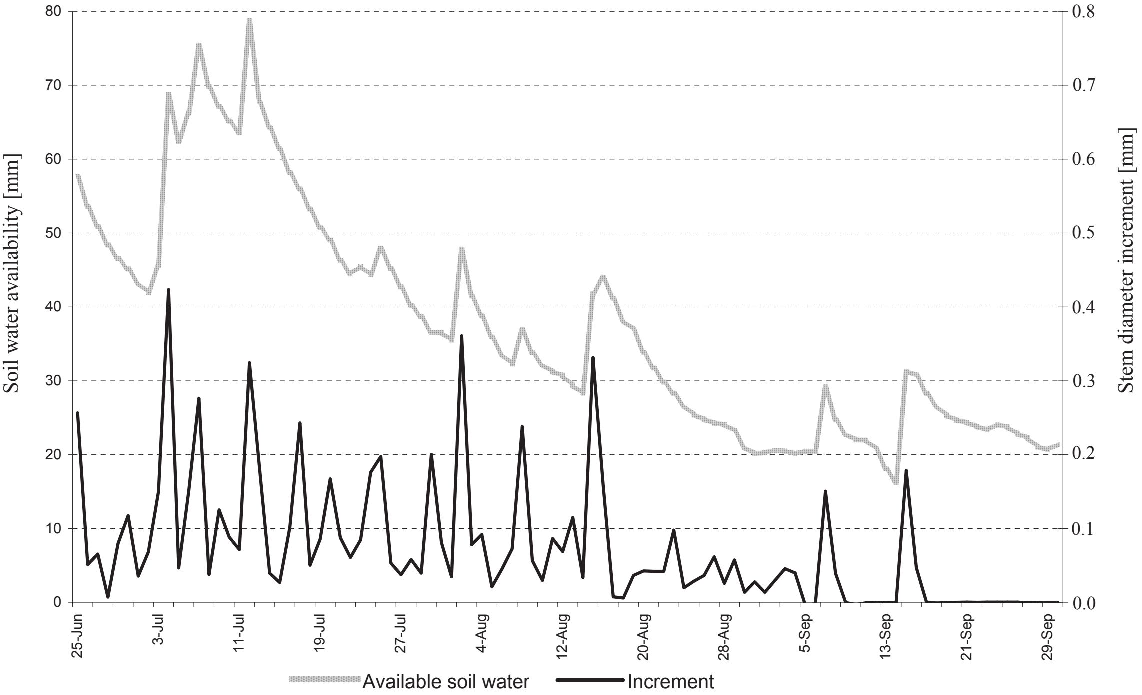


Fig. 11. Available soil water in the layer 0–0.45 m, and diurnal intensity of stem diameter increment during the summer and the beginning of autumn 2008

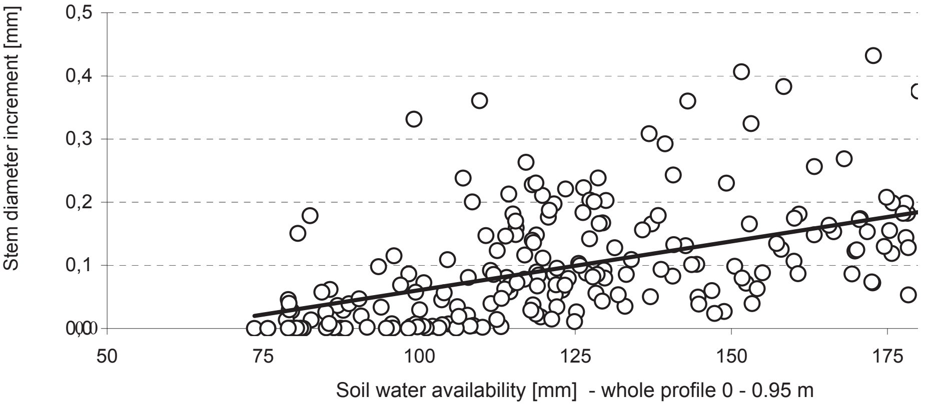


Fig. 12. Relationship between the amounts of available soil water in the layer 0–0.95 m and the diurnal stem diameter icrement

Table 3. Correlation coefficients describing the relationship between stem diameter increment [mm] and the soil water availability [mm] in different layers

Soil layer	Correlation coefficients	
	Days with rain included	Days with rain excluded
0–0.15 m	0.467	0.579
0.15–0.25 m	0.525	0.666
0.25–0.35 m	0.550	0.708
0.35–0.45 m	0.551	0.711
0.45–0.55 m	0.550	0.713
0.55–0.65 m	0.548	0.715
0.65–0.75 m	0.544	0.715
0.75–0.85 m	0.536	0.714
0.85–0.95 m	0.522	0.708
0–0.95 m	0.522	0.698

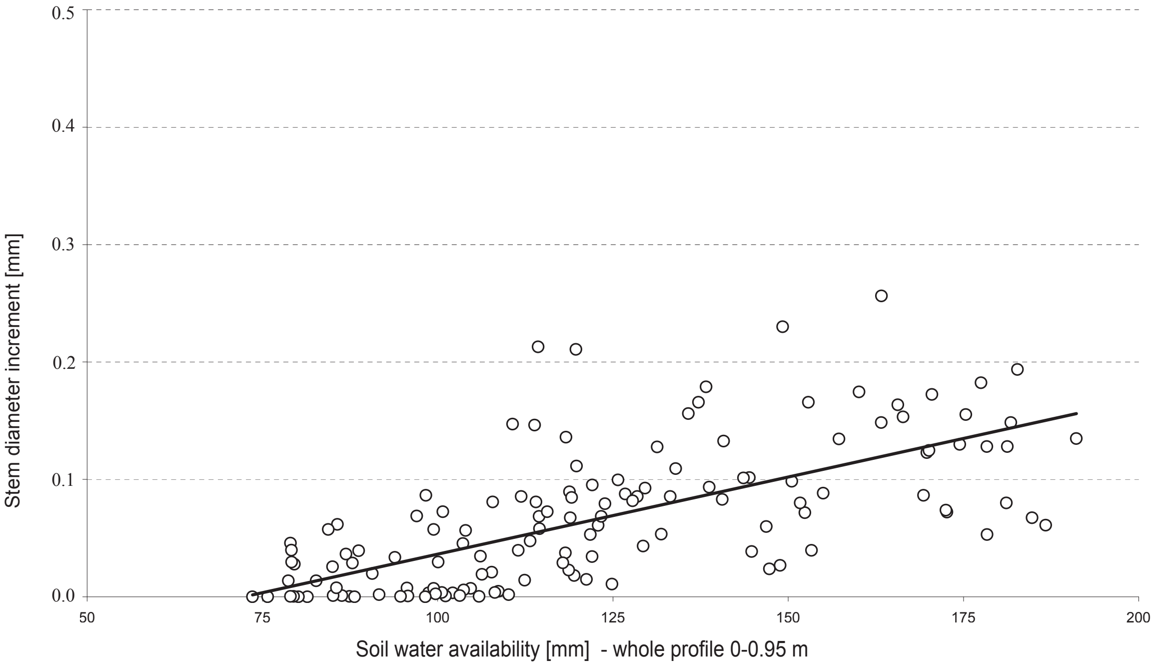


Fig. 13. Relationship between the amounts of available soil water in the layer 0–0.95 m and the diurnal stem diameter increment. The days with occurrence of precipitation were excluded in this correlation.

Discussion

The seasonal dynamics of soil moisture was typical with a large supply of available water at the beginning of spring after snow melting. The second period of the highest soil moisture values appears usually after summer rainfalls, especially in June and July which are the two months with the highest amounts of precipitation in the conditions of the Czech Republic. By contrast, shortage of soil water content was recorded at the end of summer in both of the monitored years. Such decrease of soil moisture occurred due to low precipitation and high evapotranspiration rates during this period. The soil moisture temporal dynamics was obviously depth dependent and was also more pronounced closer to the soil surface, where soil is subjected to the root water uptake and rainfall events. Indeed, the widest range (from the field capacity to the wilting point) of soil moisture values were observed in the upper layers 0–15 and 15–25. Similar results had been already observed by Loague (1992), Hupet and Vanclooster (2002). The temporal dynamics in the intermediate layers is clearly more attenuated. Nevertheless, these layers become progressively drier in response to the root water uptake combined with the upward flux. Within the deeper layers, the temporal persistence of some dry and wet zones within the field remains high. The persistence of drier zones can be explained by the sandy material from the disintegrating gneiss underlying the loamy soil. Naturally, it is well known that the thickness of the loamy layer is quite variable within the region but also within fields (Dudal, 1953). It is therefore assumed that the dry sampling locations are situated where the loamy soil is shallow, leading to measuring the soil moisture within the transition zone between the loamy soil and the sandy material. Visual observations of the soil profile during the gravimetric sampling confirm this hypothesis. On the other hand, some sampling locations are very wet in depth 0.3 and 0.4 m and it is hypothesised that a fine textured layer at this location leads locally to a perched water table.

The soil moisture data set collected in this study allows investigation of the relationship between the field-scale means and variance of soil moisture content over time. If such relationship exists, it can be of great significance, for example to optimise the number of samples required to estimate the mean value within a specified limit of error. Our results demonstrate that the spatial variability linearly decreases with the increasing mean soil moisture values. This negative correlation is consistent with the previous findings of e.g. Famiglietti et al. (1999) or Hupet and Vanclooster (2002). Nevertheless, observed results are in contrast with other previous investigations (e.g. Hills and Reynolds, 1969; Hennenger et al., 1976; Famiglietti et al., 1998). However, most of the disagreeing studies were conducted on experimental sites with much more pronounced topographic features. The widest range of variability during the dry period was observed in the layer 0.35–0.45 m. We assume on the grounds of the visual assessment of soil profile during the gravimetric sampling that the higher variability of soil moisture in deeper layers appears just because there are places with occurrence of sandy material mentioned above. The soil water from these fields can drain to the deeper layers and thus the soil get dry. During the wettest days was the layer 0.35–0.45 much more homogenous and also reached the highest soil water content. With an adoption of the term soil available water, which is the water up the wilting point, and providing that the majority of the roots are located in the profile 0–0.45 m, we can calculate how much water in this layer could be used by the plants. Generally, the amount of the available soil water fluctuated between field capacity and the stress point. Our results showed there was enough available water for the poplars to grow across the whole investigated area almost during the whole season. Nevertheless, in the driest period (the end of summer 2008 and 2009) the soil water availability decreased under the level of stress point and in some rare cases even near the wilting point at some places of the investigated plot (the places where the sandy soil was observed). Note there is quite significant positive correlation between soil water availability and the spatial variability expressed as the standard deviation, which is in the opposite with the same correlation of soil moisture and its spatial variability. The main explanation is that when the soil water availability decrease under the zero level, the whole plot seems to be very homogenous from this point of view whereas the soil moisture values are different. On the other hand, when the upper soil profile is saturated with water, the moisture availability is spatial homogenous only in the moment of the saturation and some while after. Because of the draining to the deeper layers and due to evapotranspiration, the spatial variability raise very soon.

If we evaluate the reaction of poplars to the water stress, it seems to be very suitable to observe the stem diameter increment and the available water content at the same time. It is well known that trees can tolerate longer periods of low soil water content than herbaceous plants through specialized long- and short-term physiological, phenological, anatomical, and morphological adaptations (Ludlow, 1989), such as growth reduction, stomatal closure, and osmotic adjustment (Hsiao and Acevedo, 1974). Poplars typically respond to water stress by closing stomata (Schulte et al., 1987; Bassman and Zwier, 1991; Dickmann and Pregitzer, 1992), although considerable genotypic variation can occur. Our results showed that if there was less than approximately 100 mm of available water in the whole profile (0–0.95 m), the stem volume stopped to increase. At this time, we have also observed that this clone shows a distinct tendency to abscise leaves in the lower crown as water stress increases. We can define this value of available water content as so-called stress (refill) point, which is described as the soil water content below which plant growth is measurably decreased (Campbell and Campbell, 1982). With the assumption, that the maximal available-water-holding capacity of the whole profile was determined as 194 mm, we can roughly estimate that the stress point of poplar clone J-105 is near the half of the range between the wilting point and the field capacity, which confirms the generally used conservative value of stress point as 0.5* (PAW) – plant available water (e.g. Charlesworth and Stirzaker, 2008).

Generally, growth is the biological phenomenon of increase in size with time. Growth involves the formation, differentiation and expansion of new cells, tissues or organs. The sudden increase in tree diameter often observed after rain is not due to growth but reflects the saturation of shrunk xylem and other stem tissues with water after some drier period (Offenthaler et al., 2001; Herzog et al., 1995). That's why we found stronger correlation between available soil water content and the stem diameter increment after we had omitted the day with the occurrence of precipitation. The highest correlation coefficients were recorded in the profile 0.45–0.85 m. But it doesn´t have to only mean, that in this depth is the strongest linkage between the soil water availability and stem increment and thus that there is most of the root system. It can also represent a time delay which could be theoretically the same for percolation in this depths and the reaction of growth on changed soil moisture in upper layers. Of course, the biomass yields are not influenced only by the water deficit, but very important role play solar radiation, temperature, available nutrients, etc. (Cannell et al., 1987; Han et al., 2003; Lindroth and Båth, 1999; Schneider et al., 2001). As an illustrative example, we provided a simple approach to the relation between solar radiation and stem biomass increment in Table 4. Naturally, higher solar interception leads to a certain extent, to higher photosynthetic activity, and thus to higher yields of biomass.

Table 4. The basic statistics values of stem diameter increment [mm] for different ranges of global radiation [MJ] reveal the relationship between the radiation and biomass increment.

Daily totals of global radiation [MJ]	The basic statistics of daily stem diameter increment [mm]				
	Standard deviation	*Average*	*Median*	*Maximum*	*Minimum*
10–15	0.068	0.048	0.004	0.230	–0.002
15–20	0.050	0.041	0.021	0.166	–0.003
20–25	0.054	0.083	0.081	0.256	0.000
25–30	0.055	0.093	0.072	0.194	0.034

The results of this study seem to be as a suitable material for creating and calibrating a dynamics crop model applicable for SRC. In further studies, other factors like solar radiation, temperature, transpiration, nutrients availability, dynamics of leaf area index and phenology have to be involved to the broad access of modelling. After necessary parameterization and validation, the utilization of such tool could contribute to optimize the management strategies of growing SRC and also to choose the potential areas suitable for SRC.

Acknowledgement

The presented study was supported by In-house Grant Agency at MUAF in Brno no. IGA 14/2009, In-house Grant Agency at Mendel University in Brno no. TP 11/2010 and by the Research plan no. MSM 6215648905 "Biological and technological aspects of the sustainability of controlled ecosystems and their adaptability to climate change" financed by the Ministry of Education, Youth and Sports of the Czech Republic.

References

Bassman, J. H., Zwier, J.C. 1991. Gas exchange characteristics of Populus trichocarpa and Populus trichocarpa x Populus deltoides clones. *Tree Physiol.*, 8: 145–159.

Braatne, J.H., Hinckley, T.M., Stettler, R.F. 1992. Influence of soil water on the physiological and morphological components of plant water balance in Populus trichocarpa, Populus deltoides and their F1 hybrids. *Tree Physiol.*, 11: 325–339.

Campbell, G.S., Campbell, M.D. 1982. Irrigation scheduling using soil moisture measurements: Theory and practice. *Adv. Irrig.*,1: 25–42.

Cannell, M.G.R., Milne, R., Shepard, L.J., Unsworth, M.H. 1987. Radiation interception and productivity of willow. *J. Appl.Ecol.*, 24: 261–278.

Charlesworth, P., Stirzaker, R.J. 2008. Irrigation scheduling: Soil water status. In Stanley W. T. (ed.). *Encyclopedia of water science*. Boca Raton: Taylor & Francis Group, p. 611–614.

Deckmyn, G., Laureysens, I., Garcia, J., Muys, B., Ceulemans, R. 2004. Poplar growth and yield in short rotation coppice: model simulations using the process model SECRETS. *Biomass Bioenerg.,* 26: 221–227.

Dickmann, D.I., Pregitzer, K.S. 1992. The structure and dynamics of woody plant root systems. In Mitchell, C.P., Ford-Robertson, J.B., Hinckley, T., Sennerby-Forsse L. (eds). *Ecophysiology of short rotation forest crops*. New York: Elsevier Applied Science, p. 95–123.

Dudal, R. 1953. Etude morfologique et génétique d´une séquence de sols sur limon loessique [The study of morphology and genetic evolution of loess soils on silt]. *Agricultura*, 2: 119–163.

Fajman, M., Palát, M., Sedlák, P. 2009. Estimation of the yield of poplars in plantations of fast-growing species within current results. *Acta Univ. agric. silvic. Mendelianae Brunensis*, 2: 25–36.

Famiglietti, J. S., Rudnicki, J.W., Rodell, M. 1998. Variability in surface moisture content along a hillslope transect: Rattlesnake Hill, Texas. *J. Hydrol.*, 210: 259–281.

Famiglietti, J. S., Devereaux, J. A., Laymon, C. A., Tsegaye, T., Houser, P. R., Jackson, T. J., Graham, S. T., Rodell, M., van Oevelen, P. J. 1999. Ground–based investigation of soil moisture variability within remote sensing footprint during the Southern Great Plains 1997 (SGP97) Hydrology Experiment. *Wat. Resour. Res.*, 6: 1839–1851.

Han, D., O´Kiely, P., Sun, D.W. 2003. Application of water-stress models to estimate the herbage dry meter yield of a permanent grassland pasture Sward regrowth. *Biosyst. Engng*, 84: 101–111.

Henninger, D.L., Peterson, G.W., Engman, E.T. 1976. Surface soil moisture within a watershed-variations, factors influencing, and relationships to surface runoff. *Soil Sci. Soc. Am. J.*, 40: 773–776.

Herzog, K.M., Häsler, R., Thum, R. 1995. Diurnal changes in the radius of a subalpine Norway spruce stem: their relation to the sap flow and their use to estimate transpiration. *Trees*, 10: 94–101.

Hills, T.C., Reynolds, S.G. 1969. Illustrations of soil moisture variability in selected areas and plots of different sizes. *J. Hydrol.*, 8: 27–47.

Hsiao, T. C., Acevado, E. 1974. Plant response to water deficits, water–use efficiency, and drought resistance. *Agric. Meteorol.*, 14: 59–84.

Hupet, F., Vanclooster, M. 2002. Intraseasonal dynamics of soil moisture variability within a small agricultural maize cropped field. *J. Hydrol.,* 261: 86–101.

Isebrands, J.G., Karnonsky, D.F. 2001. Environmental benefits of poplar culture. In Dickmann, D.I., Isebrands, J.G., Eckenwalder, J.E., Richardson, J., (eds). *Poplar culture in North Ame-rica.* Ottawa: National Research Council of Canada, p. 207–218.

Kauter, D., Lewandowski, I., Claupein, W. 2003. Quantity and quality of harvestable biomass from Populus short rotation coppice for solid fuel use a review of the physiological basis and management practices. *Biomass Bioenerg.,* 24: 411–427.

Lindroth, A., Båth, A.1999. Assessment of regional willow coppice yield in Sweden on basis of water availability. *Forest Ecol. Mgmt*, 121: 57–65.

Loague, K.1992. Soil water content at R-5. Part 1. Spatial and temporal variability. *J. Hydrol.,* 139: 233–251.

Ludlow, M.M. 1989. Strategies of response to water stress. In Kreeb, K., Richter, H., Hinckley, M.

(eds). *Structural and functional responses to environmental stresses: Water shortage*. The Hague: SPB Academic Publishing, p. 269–281.

Offenthaler, I., Hietz, P., Richter, H. 2001. Wood diameter indicates diurnal and long-term patterns of xylem water potential in Norway spruce. *Trees*, 15: 215–221.

Schneider, L.C., Kinzig, A.P., Larson, E.D., Solórzano, L.A. 2001. Method for spatially explicit calculations of potential biomass yields and assessment of land availability for biomass energy production in Northeastern Brazil. *Agric. Ecosyst. Envir.*, 84: 207–226.

Schulte, P.J., Hinckley, T.M., Stettler, R.F. 1987. Stomatal responses of Populus to leaf water potential. *Can. J. Bot.*, 65: 255–260.

Slatter, F.M., Heaton, R.J., Randerson, P.F. 2001. In Kyritsis S. (ed.). *First World Conference on Biomass for Energy and Industry. Proceedings of the Conference held in Sevilla, June 5–9, 2000, Spain*. London: James & James, 1570–1573.

Trnka, M., Trnka, M., Fialová, J., Koutecký, V., Fajman, M., Žalud, Z., Hejduk, S. 2008. Biomass production and survival rates of selected poplar clones grown under a short-rotation on arable land. *Pl. Soil Envir.*, 54: 78–88.

Updegraff, K., Baughman, M.J., Taff, S.J. 2004. Environmental benefits of cropland conversion to hybrid poplar: economic and policy consideration. *Biomass Bioenerg.,* 27: 411–428.

Weger, J., Havlíčková, K. (eds). 2003. *Biomasa – obnovitelný zdroj energie v krajině* [Biomass – renewable source of energy in countryside]. Průhonice: VÚKOZ. 51 p.

Dostupnost vody v porostu rychle rostoucích dřevin (*Populus nigra* × *P. maximowiczii*) v podmínkach Českomoravské vrchoviny

Souhrn

Cílem této studie je přispět k diskuzi o efektivitě produkce rychle rostoucích dřevin (RRD) na vybraných stanovištích a zároveň na základě přesných bioklimatologických měření definovat a modelovat ideální podmínky pro jejich pěstování. Předkládaná publikace se zabývá především vztahy mezi přírůsty biomasy a dostupností vody, jakožto limitního faktoru. Dále obecně pojednává o dynamice a prostorové variabilitě vlhkostního režimu půdy v porostu RRD. Pozorování a měření probíhaly na topolové plantáži nacházející se na lokalitě Domanínek (Česká republika, 49° 32' s. š. a 16° 15' v. d., 530 m n. m.) v katastrálním území města Bystřice nad Pernštejnem. Jedná se o monokulturní plantáž v ČR v současné době nejpoužívanějšího rychle rostoucího topolového klonu J-105 (*P. nigra* × *P. maximowiczii*) o celkové rozloze 4 ha. Ačkoli zdejší klimatické podmínky pro pěstování topolových porostů RRD dosahují téměř limitních hodnot, stanoviště je zcela produkce schopné a to zejména díky hlubokému půdnímu profilu.

Výsledky týkající se dynamiky půdní vlhkosti a její prostorové variability potvrzují, že zásoba vody v půdě v průběhu vegetační sezóny postupně klesá. K nasycení dochází obvykle brzy na jaře po tání sněhu a po intenzivních letních deštích. V těchto obdobích je rovněž prostorová variabilita půdní vlhkosti nejnižší. Po déletrvajících přísušcích, které byly zaznamenány v obou sledovaných letech (2008 a 2009) na konci léta, dochází ke značnému poklesu půdní vláhy až pod bod snížené dostupnosti. Tyto nejsušší periody byly naopak charakteristické nejvyšší prostorovou variabilitou. V obdobích sucha byl rovněž pozorován průkazný pokles u přírůstů na kmenech a byl tak definován bod snížené dostupnosti pro klon J-105 nacházející se přibližně v polovině mezi bodem vadnutí a polní kapacitou. Získané vztahy a výsledky mohou sloužit jako podklady pro tvorbu nových dynamických růstových modelů aplikovatelných pro RRD, ale i pro parametrizaci a validaci modelů stávajících. V dalších studiích je nutné zohlednit vliv dalších faktorů na tvorbu a dynamiku přírůstů biomasy. Jedná se především o solární radiaci, teplotu, dostupnost živin v půdě, dynamiku vývoje listové plochy a fenologii porostu. Po nezbytné parametrizaci a prověření vypovídací schopnosti modelů by bylo s jejich využitím možno přispět k optimalizaci pěstování RRD, k selekci nových stanovišť a odhadu možných výnosů.

Received January 7, 2010
Accepted April 4, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Biomass production of *Viola reichenbachiana* L. in submountain beech forest of Kremnické vrchy Mts (Western Carpathians, Slovakia)

Rastislav Janík

Institute of Forest Ecology of the Slovak Academy of Sciences, Štúrova 2, Zvolen, Slovak Republic,
E-mail: janik@savzv.sk

Abstract

Janík, R. 2010. Biomass production of *Viola reichenbachiana* L. in submountain beech forest of Kremnické vrchy Mts (Western Carpathians, Slovakia). 2010. *Folia oecol.*, 37: 35–41.

Presented are our research results on biomass production of *Viola reichenbachiana* L. in a submountain beech stand with graded stocking density levels. The study ran at the Beech Ecological Experimental Site Kremnické vrchy Mts in years 1993–94 and 2005–06. The required density values were obtained by a controlled cutting intervention. Optimum, that means maximum production values of above ground as well as belowground biomass components were recorded on control plot without intervention. The maximum amount of above ground biomass representing 41.2 kg ha^{-1} was observed in summer aspect 1994, maximum of belowground biomass 67.2 kg ha^{-1} occurred in autumn of the same year. Most significant statistical differences were observed between clear-cut plot and plot treated by medium intensive regeneration cutting.

Key words

biomass production, submountain beech forest, *Viola reichenbachiana*, Western Carpathians

Introduction

Today, production potential of forest phytocoenoses is of increasing importance. This holds not only for production of wood mass – one of few permanent renewable natural resources. In this context emerges also the issue of production of herb layers in forest ecosystems. Herb component of a forest can be discussed in several different contexts. From the viewpoint of ecology, herb layers are inseparable constituent of forest ecosystems, and their role is crucial in almost all aspects (food webs, physiology, production, ecological indicators). For commercial purposes, herb layer is an important factor in assessment of effectiveness of regeneration cutting treatments in various geographic areas. Security of forest stands after a cutting cannot be separated from forest reproduction. Inappropriate cutting can disturb ecological equilibrium to serious extent. High production value of herb component, especially grass taxons (Fiala, 1996a, 1996b; Tůma, 1996) is frequently a dramatic problem in forest regeneration process.

Relevance of better understanding of the role of herb layer in forest ecosystems is also evident on the number of authors studying this problem: Mölder, A. et al. (2008), Kuklová and Kukla (2006, 2008), Schieber (2006, 2007), Kollár et al. (2008), Kontriš J. et al. (1988), Križová (1993), Križová and Mihálik (1985), Kubíček (1983), Kubíček et al. (2006, 2008), Łysik (2009), Chmura (2008), Havranová (2009) and many others.

Material and methods

Our research on primary production of herbs was pursued in years 1993–1994, 2005–2006, in a beech stand with graded stocking density (0.0; 0.3; 0.5; 0.7; 0.9) at the Ecological Experimental Site (EES) Kremnické vrchy Mts. The locality is situated in moderately warm climatic region, moderately warm and wet hilly climatic district with a mean annual temperature $t_{(1951–1980)}$ of 6.8 °C. The studied stand grows on a regular, WSW oriented slope with an inclination of 12.5–18 °C, at an altitude of 450–510 m (Kellerová, 2009). The dominant soil substrate consists of andesite tuffaceous agglomerates from which there has been developed a saturated variant of cambisol andosolic with high skeleton content, increasing with depth. The soil body is layered, built by the main and basal system of layers (Pichler, 1996). More details on the local soils can be found in Kukla (2002), Širáň (2003) and Dubová and Bublinec (2006). The plots belong to nutrient order B, group of forest types Fagetum pauper, lower degree and forest type Carex pilosa-nudum (Hančinský, 1972). The names of plant taxa have been given in the sense of Dostál (1989).

Above ground biomass component of herbs was determined by the method of indirect sampling designed by Kubíček (1977). As the study plot was chosen a plot serving for phytocoenological relevés (20 × 20 m). The main interest was put on the as objective as possible description of the studied phytocoenosis also with respect to non-uniform herb cover in the understorey, and so also with respect to more species showing irregular distribution across the plot. Within this plot, there have been established five representative mini-plots, each 1 m^2 in area for production-ecological research sensu Kubíček (1983). To avoid subjectivity, the plots were selected by using the table of random numbers (Šmelko, 1974). As individual plants were considered separate stalks without stolons. In some species, especially grasses, individuals were considered separate stems or leaves sprouting from a bunch (*Bromus ramosus* subsp. *benekenii, Brachypodium sylvaticum, Carex digitata.* Individuals of *Veronica officinalis* were defined as rooted stalks. In distinguishing between above ground and below-ground biomass, there were sampled entire herbs, and root systems were separated at the interface between soil surface and atmosphere. Measurements were taken across the entire growing period. The herbs were sampled in close proximity to the study plot, by one from each species (about 30 inds). In the laboratory, the material was dried and weighed, and the results were converted to unit mass and area (m^2, ha^{-1}). The frequency data were calculated according to the formula: F = M/n . 100, where F is the species's frequency on the representative plot in %, n is number of plots with occurrence of this species and N is the total number of squares on each study plot (in our case 5).

For quantification and evaluation of below-ground biomass we used the method described by Fiala (in Rychnovská et al., 1987). A special care was devoted to meticulous separation of the clear mass of "live" roots from undesired admixtures (soil fractions, dead roots, insects).

Results and discussion

Viola reichenbachiana, representing not even one per cent either in total above ground or below-ground biomass of all herbs, does not belong to dominant species as far as production capacity of forest ecosystems. The species is important due to its high frequency on individual partial plots at the study site. The frequency value obtained on the former clear cut was above 80%, on the control plot without intervention it did not sink below 40%.

Production on plot H with stocking 0.0

In the spring aspect 1993, the clear-cut plot produced 15.2 kg ha^{-1} of above ground biomass of this type. The root system weight did not exceed 4.0 kg ha^{-1}. The frequency values reached up to 40%. In the following summer and autumnal aspect, biomass of above ground organs was progressively reduced down to 8.4 kg ha^{-1} in autumn 1993. The trend in belowground biomass was opposite – an increase to 7.2 kg ha^{-1}; obviously thanks to nutrient reserves deposed in roots. The frequency values did not sink below 80%.

In 1994 was recorded a similar trend in biomass creation, with maximum values, however, in summer months. There were also differences in above ground and in belowground biomass amounts between the years. Good precipitation conditions in winter 1993–1994, with 289.1 mm fallen on the plot compared to 167.5 mm in winter 1992–1993 were followed by 259.9 mm in spring 1994 but only 55.0 mm in spring 1993. In total, much more favourable situation in throughfall was in 1994 (almost double amounts) than in year 1993. This fact was reflected in biomass production increase to 34.2 kg ha^{-1} in each component, and frequency values close to 100%.

In years 2005 and 2006, the production of the studied taxon was close to zero. Only in spring 2006 we recorded 0.3 kg ha^{-1} and 0.1 kg ha^{-1} of above ground and belowground biomass, respectively. This conspicuous reduction was caused by strongly reduced light supply inside the new-forming stand at stage of young growth exceeding 8–10m in height at the time. The frequency value was almost 30%.

The values of above ground and belowground biomass ranged between 51–76%, which indicates certain lack of homogeneity of the studied stands. The standard deviation values were relatively low: 9.6 and 12.4 in above ground and belowground biomass, respectively. Other characteristics of measure and position are in Table 2.

Pair testing revealed that the most significant differences were between plots H and S and between plots H and M in case of above ground biomass; and between plots H and M and between plots H and K in case of belowground biomass. The results of testing among the plots are summarised in Table 3.

Table 2. Descriptive statistic of biomass production of *Viola reichenbachiana* L. on the EES Kremnické vrchy Mts

Plots	H		I		S		M		K	
	Above ground	Below ground	Above ground	Below ground	Above ground	Below ground	Above ground	Below ground	Above ground	Below ground
Average	18.6	16.3	9.3	9.3	3.2	4.8	3.0	6.8	17.5	37.9
Median	17.0	15.2	7.1	9.2	3.4	4.8	2.6	4.7	15.9	39.4
Modus	15.2	7.2	5 .6	8.0	3.2	2.3	2.3	4.0	15.1	34.5
Geom. Mean	16.7	12.0	7.3	7.5	2.7	3.0	2.6	5.3	11.8	23.3
Variance	91.6	153.1	62.5	32.7	3.6	15.1	3.1	34.1	182.4	637.1
Std. Dev.	9.6	12.4	7.9	5.7	1.9	3.9	1.8	5.8	13.5	25.2
Std. error	3.9	5.1	3.2	2.3	0.8	1.6	0.7	2.4	5.5	10.3
Min.	8.4	3.8	2.9	2.8	0.8	0.5	1.1	2.6	1.3	1.3
Max.	34.2	34.2	24.7	16.3	6.4	9.6	6.0	18.0	41.2	67.2
Range	25.8	30.4	21.8	13.5	5.6	9.1	4.9	15.4	39.9	65.9
Vx [%]	51.6	76.0	84.9	61.9	55.9	69.2	69.2	85.3	77.1	63.9

H, clear cut (stocking 0.0); I, intensive cutting (stocking 0.3); S, medium (stocking 0.5); M, moderate (stocking 0.7); K, control (stocking 0.9); Vx [%], coefficient of variation; Std. Dev., standard deviation

Table 3. Comparison and testing of biomass production of *Viola reichenbachiana* L on the EES Kremnické vrchy Mts between partial plots

Plots	H		I		S		M		K	
	Above ground	Below ground	Above ground	Below ground	Above ground	Below ground	Above ground	Below ground	Above ground	Below ground
H Above ground	–	–	–1.7*	–	–2.8**	–	–2.8**	–	–0.2	–
H Below ground	–	–	–	–0.9	–	–0.2	–	–1.5*	–	1.3*
I Above ground	1.7*	–	–	–	–1.8*	–	–2.2**	–	1.2*	–
I Below ground	–	0.9	–	–	–	–1.7*	–	–0.7	–	1.8*
S Above ground	2.8**	–	1.8*	–	–	–	–0.2	–	2.0**	–
S Below ground	–	0.2	–	1.7*	–	–	–	0.7	–	2.2**
M Above ground	2.8**	–	2.2**	–	0.2	–	–	–	2.0**	–
M Below ground	–	1.5*	–	0.7	–	–0.2	–	–	–	1.8**
K Above ground	0.2	–	–1.2*	–	–2.0**	–	–2.0**	–	–	–
K Below ground	–	–1.3*	–	–1.8**	–	–2.2**	–	–1.8**	–	–

Above ground, aboveground biomass production; Below ground, below ground biomass production; H, clear cut (stocking 0.0); I, intensive cutting (stocking 0.3); S, medium (stocking 0.5); M, moderate (stocking 0.7); K, control (stocking 0.9); *statistically significant on the $p < 0.05$; **statistically very significant on the $p < 0.01$

Production on plot I with stocking 0.3

The production dynamics is illustrated in Table 1. In years 1993–94, we can see an evident decrease in above ground as well as underground biomass production compared to plot H. For the overall biomass it makes 58%. In this period, there were produced on average 5.2 kg ha^{-1} of above ground and 9.3 kg ha^{-1} of belowground biomass. Frequency values ranged from 40% (summer 1994) to 80% (spring 1993). Maximum production values of above ground and belowground biomass were recorded in spring 1994 (24.7 kg ha^{-1} and 16.3 kg ha^{-1}, respectively). In years 2005–2006, dry biomass production was observed strongly reduced both in above ground and in belowground biomass: on average 1.7 kg ha^{-1} and 2.1 kg ha^{-1}, respectively. Frequency values were between 60–70%.

Also on this plot, the values of variation coefficient were relatively high: almost 85% for above ground biomass and 62% for belowground biomass. On the other hand, the standard deviation in belowground biomass was small (1.9), and variation range relatively narrow (13.5).

The biggest differences were recorded between plots I and M for above ground biomass, and between plots I and K for belowground biomass.

Production on plot S with stocking 0.5, and on plot M with stocking 0.7

The course of production on plot S was very similar to plot M. In both cases, production gradually decreased over the whole period of study. The value of above ground biomass production on plot S (stocking density 0.5) was 2.2 kg ha^{-1}; in case of belowground biomass it was 3.4 kg ha^{-1}. The corresponding values on plot M (stocking 0.7) were 1.9 kg of above ground and 4.3 kg ha^{-1} of belowground biomass. The maximum amount of above ground biomass on plot S was recorded in spring 1994 – 6.4 kg ha^{-1}, maximum of belowground biomass in summer 1994 – 9.6 kg ha^{-1}. The maximum of above ground biomass on plot M was obtained in autumn 93 – 6.0 kg ha^{-1}, belowground biomass reached its maximum in autumn 1993 – 18.0 kg ha^{-1}. Frequency values were the lowest among the hitherto reported: 20–40%.

Variation coefficient maintained at high levels: 56% (S) and 81% (M). The biggest differences were found between plots S and H and between plots S and K.

Production on plot H with stocking 0.0

The control, untreated plot, displayed interesting facts. The share of above ground biomass produced by the species *Viola reichenbachiana* had increased almost up to 14% of the total biomass amount produced by all the herb taxons on the plot. In case of belowground biomass, it made even 24% of the total dry weight of belowground organs of all the herb species on the plot. Max. values of above ground biomass were obtained in summer 1994 (41.2 kg ha^{-1}). Belowground biomass reached its maximum in autumn 1994 with a value of almost 68.0 kg ha^{-1}. The max. values were higher than on the plot without parent stand: by 7.0 kg ha^{-1} in case of above ground and by more than 27.0 kg ha^{-1} in case of belowground biomass. This phenomenon was evidently caused by the light demands of the studied species. Mölder et al. (2008) studied correlation between production of herb species and tree canopy density, and they obtained the highest correlation coefficient (0.71) namely for *Viola reichenbachiana*. This means that this species is distinctly shadow-tolerating. This fact has also been confirmed by Kollár et al. (2008) who obtained in conditions of Carici fritschii-Quercetum xerophilous type in Moravia only 1.0 kg ha^{-1} of above ground biomass and 3.0 kg ha^{-1} belowground biomass of this species. Kubíček et al. (2006) report production values of this species in hard broadleaved forests near the Skalica town (Western Slovakia) being 13.0 kg ha^{-1} in case of aboveground biomass and 18.0 kg ha^{-1} in case of belowground biomass. In the same locality, but in forests of type ash-poplar floodplain, in which more light reached the forest ground, the production dropped to 1.0 kg ha^{-1} in case of above ground as well as in case of belowground biomass. Very similar production values report the authors also for the locality Kútsky les with dominant heliophytes *Urtica dioica* and *Alliaria petiolata*. Also on untreated plot, we obtained rather high variation coefficients: 77% in above ground and 66.5% in belowground biomass.

Statistically significant differences were obtained in almost all comparisons with the other plots (Table 3).

Conclusions

In years 1993–94, we evaluated production capacity of *Viola reichenbachiana* in varying conditions of submountain beech forests at the BEES Kremnické vrchy Mts. The experimental site consists of five partial plots differing in stocking density. We used the method of indirect sampling proposed by Kubíček (1983). The highest values of above ground biomass production were recorded in summer 1994 on the untreated, control plot: 41.2 kg ha^{-1}. The highest underground biomass values were obtained in the autumnal aspect 1994, on the control plot again: 67.2 kg ha^{-1}. In general, belowground biomass values culminate in autumn.

On the other hand, the highest frequency values were obtained on clear-cut plot H, about 80% on average.

The highest values of variation coefficient were observed on plot M: 69.2% for above ground and almost 86% for belowground biomass.

Pair tests revealed that the biggest differences in above ground biomass production were between plots

Table 1. Above and below ground biomass production of *Viola reichenbachiana* L.on the EES Kremnické vrchy Mts

Plots	H			I			S			M			K		
Biomass production	Above ground	Below ground	F	Above ground	Below ground	F	Above ground	Below ground	F	Above ground	Below ground	F	Above ground	Below ground	F
Period	kg	ha^{-1}	%	kg	ha^{-1}	%	kg	ha^{-1}	%	kg	ha^{-1}	%	kg	ha^{-1}	%
Spring 1993	15.2	3.8	60	4.8	3.2	80	3.6	7.2	20	2.8	2.8	40	9.4	18.8	40
Summer 1993	10.6	5.9	80	5.6	2.8	60	0.8	1.2	20	4.0	4.0	40	1.3	1.3	40
Autumn 1993	8.4	7..2	80	8.6	10.3	60	3.2	7.8	40	6.0	18.0	40	15.1	44.2	40
Total	**34.2**	**16.9**		**19.0**	**16.3**		**7.6**	**16.2**		**10.8**	**24.8**		**25.8**	**64.3**	
Spring 1994	24.5	23.1	100	24.7	16.3	60	1.8	2.3	20	1.1	2.6	40	16.7	34.5	40
Summer 1994	34.2	34.2	100	9.0	15.0	40	6.4	9.6	40	1.8	5.4	40	41.2	61.8	40
Autumn 1994	18.8	23.5	80	2.9	8.0	60	3.5	0.5	20	2.3	8.0	40	21.5	67.2	40
Total	**77.5**	**80.8**	–	**36.6**	**39.3**		**11.7**	**12.4**		**5.2**	**16.0**		**79.4**	**164.0**	–
Spring 2005	–	–	–	1.0	0.5	60		0.5	30	0.2	0.8	30	–	–	–
Summer 2005	–	–	–	–	–	–	–	–		–	–		–	–	–
Autumn 2005	–	–	–	2.0	1.0	60	1.0	1.0	40	0.5	1.0	30	–	–	–
Total	–	–	–	**3.0**	**1.5**		**1.5**	**1.5**		**0.7**	**1.8**	–	–	–	–
Spring 2006	0.3	0.1	30	0.8	4.0	60	0.3	0.3	40	–	–	–	–	–	–
Summer 2006	–	–	–	–	–	–	–	–		–	–	–	–	–	–
Autumn 2006	–	–	–	3.0	3.0	70	1.0	3.0	30	0.4	0.4	10	1.0	1.0	10
Total	**0.3**	**0.1**	–	**3.8**	**7.0**	–	**1.3**	**3.0**	–	**0.4**	**0.4**	–	**1.0**	**1.0**	–

H, clear cut (stocking 0.0); I, intensive cutting (stocking 0.3); S, medium (stocking 0.5); M, moderate (stocking 0.7); K, control (stocking 0.9); F, frequency

H and S, and between plots H and M. In belowground biomass was found the biggest difference between plots K and S. It follows that the intensity of management intervention has a very important influence on production capacity of individual herb taxons.

Acknowledgement

The study was supported by the Scientific Grant Agency VEGA of the Ministry of Education of the Slovak Republic and of the Slovak Academy of Science, Project No. 2/0045/08

Translated by Dagmar Kúdelová

References

Dostál, J. 1989. *Nová květena ČSSR* [New flora of the Czechoslovak Socialistic Republic]. Praha: Academia. 1548 p.

Dubová, M., Bublinec, E. 2006. Evaluation of sulphur and nitrate-nitrogen deposition to forest ecosystems. *Ekológia (Bratislava)*, 25:366–376.

Fiala, K. 1996a. Variation in total underground biomass, root growth rate rhizome formation in grass stands on deforested sotes. In *Grass ecosystems of deforested areas in the Beskydy Mts.: preliminary results* of *ecological studies*. Brno: Institute of Landscape Ecology, Academy of Sciences of the Czech Republic, p. 83–90.

Fiala, K. 1996b. Estimation of annual production and turnover rate of underground plant biomass in Calamagrostis villosa and Avenella flexuosa stands. In G*rass ecosystems of deforested areas in the Beskydy Mts.: preliminary results* of *ecological studies*. Brno: Institute of Landscape Ecology, Academy of Sciences of the Czech Republic, p. 91–96.

Hančinský, L. 1972. *Lesné typy Slovenska* [Forest types of Slovakia]. Bratislava: Príroda. 307 p.

Havranová, I. 2009. *Indikačná hodnota vybraných rastlinných druhov vo vzťahu k imisiami znečistenému prostrediu* [Indication values of selected plant species in environment under air pollution]. PhD thesis. Zvolen: Institute of Forest Ecology of the Slovak Academy of Sciences. 94 p.

Chmura, D. 2008. The slope aspect affects the heterogenity and growth of ground vegetation in deciduous temperate forest. *Pol. J. Ecol.*, 56: 463–470.

Kellerová, D. 2009. Changes in air quality in different phases of forest management process in a submountain beech ecosystem (West Carpathian Mts.) *J. Forest Sci.*, 55: 368–375.

Kollár, J., Kubíček, F., Šimonovič, V. 2008. Ecological analysis of the oak forests on the Morava river Terrace. *Ekológia (Bratislava)*, 27: 379–385.

Kontriš, J. et al. 1988. *Fytocenologické pomery a dynamika vegetácie na EES Kováčová* [Phytocoenological condition and vegetation dynamics at the EES (Ecological Experimental Site) Kováčová]. Final report of the project No. VI-4-2/07. Zvolen: Institute of Forest Ecology of the Slovak Academy of Sciences. 47 p.

Križová, E. 1993. Primárna produkcia nadzemnej biomasy bylinnej vrstvy vybraných lesných typov EES Kováčová [Primary above-ground biomass production in herb layers of selected forest types at the EES Kováčová]. *Acta Fac. for. zvolen*, 35: 99–106.

Križová, E., Mihálik, A. 1985. Príspevok k poznaniu produkcie nadzemnej biomasy bylín v jedľobučine [A contribution to knowledge about herb above-ground biomass production in fir beech forest stands]. *Acta Fac. for. zvolen*, 38: 15–40.

Kubíček, F. 1977. Metódy štúdia produktivity rastlín [Methods for plant production study]. *Acta ecol.*, 16: 8–30.

Kubíček, F. 1983. *Produkčnoekologické štúdium biomasy bylinnej vrstvy lesných spoločenstiev* [Production-ecological study of herb layer biomass in forest ecosystems]. DrSc (Doctor of Sciences) thesis. Bratislava: Institute of Experimental Biology and Ecology of CBES of the Slovak Academy of Sciences. 311 p.

Kubíček, F., Šimonovič, V., Kollár, J., Kanka, R. 2006. Production ecology of some rare forest communities on the Borská nížina lowland. *Ekológia (Bratislava)*, 25: 335–340.

Kubíček, F., Šimonovič, V., Kollár, J., Kanka, R. 2008. Herb layer biomass of the Morava river floodplain forests. *Ekológia (Bratislava)*, 27: 23–30.

Kukla, J. 2002. Variability of solutions percolated through cambisol in a beech ecosytem. *Ekológia (Bratislava)*, 21: 13–26.

Kuklová, M., Kukla, J. 2006. Natural reserve Chynoriansky luh floodplain, its ecology and biometry of dominant herb species. *Ekológia (Bratislava)*, 25: 341–351.

Kukla, J., Kuklová, M. 2008. Growth of Vaccinium myrtillus L. (Ericacea) in spruce forests damaged by air pollution. *Pol. J. Ecology*, 56: 149–155.

Łysik, M. 2009. A 13-year change in ground-layer vegetation of Carpathian beech forests. *Pol. J. Ecol.*, 57: 47–61.

Mölder, A., Römermann, M.B., Schmidt, W. 2008. Herb-layer diversity in deciduous forests: Raised by tree richness or beaten by beech? *Forest Ecol. Mgmt*, 256: 272–281.

Pichler, V. 1996. *The changes of soil moisture and of moisture potential after the reduction stocking of beech stand*. PhD thesis. Zvolen: Technical University in Zvolen, Faculty of Forestry. 83 p.

Rychnovská, M. et al. 1987. *Metody studia travinných ekosystémů* [Methods for grassland ecosystems study]. Praha: Academia. 217 p.

Schieber, B. 2006. Spring phenology of European beeach (Fagus sylvatica L.) in submountain beech forest stand with various stocking between 1995–2004. *J. Forest Sci*., 52: 208–216.

Schieber, B. 2007. Changes of flowering phenology of six herbal species in a beech forest (Central Slovakia): A decade analysis. *Polish J. Ecol.*, 55: 233–244.

Širáň, M. 2003. Teplota pôdy vo vegetačnom období vo vzťahu k jej vlhkosti [Soil temperature in the vegetation period with relationship the moisture]. In *Ochrana a využití půdy v nivních oblastech. Sborník příspěvků z konference 9. Pedologické dny. Velké Bílovice, 3.–4. září 2003*. Brno: Mendelova zemědělská a lesnická univerzita, p. 112–116.

Šmelko, Š. 1974. *Štatistické metódy v lesníctve* [Statistical methods in forestry]. Zvolen: VŠLD. 476 p.

Tůma, I. 1996. Growth of Calamagrostis arundinacea tufts on different habitats in the Beskydy Mts. In *Grass ecosystems of deforested areas in the Beskydy Mts.: preliminary results* of *ecological studies*. Brno: Institute of Landscape Ecology, Academy of Sciences of the Czech Republic, p. 111–116.

Produkcia biomasy fialky lesnej v podhorských bučinách Kremnických vrchov (Západné Karpaty)

Súhrn

V rokoch 1993-94 a 2005-06 bol v podmienkach podhorských bukových porastov Ekologického experimentálneho stacionára Kremnické vrchy uskutočnený produkčný výskum *Viola reichenbachiana*. Ťažbovým zásahom boli upravené zakmenenia na požadované hodnoty. Optimálne a teda maximálne hodnoty produkcie tak nadzemnej ako aj podzemnej biomasy boli zaznamenané na kontrolnej ploche bez zásahu. Z časového hľadiska nadzemná biomasa dosiahla maximum v letnom aspekte roku 1994 s hodnotou 41,2 kg ha^{-1}, podzemná biomasa dosiahla maximum na jeseň toho istého roku so 67,2 kg ha^{-1}. Štatisticky najvýznamnejšie rozdiely boli medzi plochami, kde bol uskutočnený holorub a plochou s miernym resp. stredne silným ťažbovo-obnovným zásahom.

Received January 28, 2010
Accepted March 10, 2009

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Allometry of winter buds in beech (*Fagus sylvatica* L.) natural regeneration with respect to its volume and dry weight estimation

Benjamín Jarčuška

Institute of Forest Ecology of the Slovak Academy of Sciences, Štúrova 2, 960 53 Zvolen, Slovak Republic, E-mail: jarcuska@savzv.sk

Abstract

Jarčuška B. 2010. Allometry of winter buds in beech (*Fagus sylvatica* L.) natural regeneration with respect to its volume and dry weight estimation. *Folia oecol.*, 37: 42–50.

Allometric relationships among bud's fresh volume (V), length (L), maximal diameter (MD), basal diameter (BD), and dry weight (W) in beech (*Fagus sylvatica* L.) saplings manifest strong mutual correlations. These correlations depend on the bud type determined by bud position on shoot, shoot type and shoot position in crown. However, in most cases the differences among the bud types are not distinct – individual types can be classified into several overlapping groups. The bud type significantly influences bud shape characterised by the ratios of BD to MD, and BD to L; on the other hand, it has no influence on MD/L and bud density (V/W). Influence of accessible light on bud shape and density also depends on bud type. For non-destructive estimation of V and W, we have prepared a regression model using as independent variable the volume of cylinder enclosing the bud (V_{cyl}). This model could explain 98% of the variation in V and W, with a relative accuracy of 6.4% for V, and 5.4% for W ($P = 0.95$). The performance of the model was verified by a test allowing us to conclude that the model outputs are comparable with directly measured values.

Key words

allometry, European beech, volume and dry weight estimation, winter bud

Introduction

The growth of plants and the other modular organisms runs through initiation of organ primordia from meristematic cells, and development of these primordia into fully grown plant organs. For permanent plants of temperate and cold zone is typical "rhythmic growth" displaying endogenous periodicity and cessation of extension. The germs of shoots developing within a given growing season had already been created in buds in the preceding vegetation period ("preformation"; Barthélémy and Caraglio, 2007).

Roloff (1987) studying the morphogenetic bud cycle of European beech (*Fagus sylvatica* L.) observed that new leaves were mostly formed in June and July; and that the growth of the leaf primordia mainly occurred in August and September. This author stated that all primordia for the next growing season had already been fully developed in the buds by August, and that at the same time there was initiated primordia formation for the year after the next. These results have been proved experimentally also by Eschrich et al. (1989). The growth of beech shoots in the current year is chiefly influenced by the amounts of assimilates created in the preceding year, and, consequently, by environmental conditions throughout this year (e.g. Masarovičová, 1985). Löf and Welander (2000), and Welander and and Ottosson (1997) have confirmed that the length and number of beech shoots in the current year was mainly dependent on environmental conditions in the preceding year (soil water content and light availability). Roloff (1987) also concluded that the environmental conditions (e.g. drought) in early summer influenced number of leaves in the next year, while late summer conditions (drought) affected the size of these leaves. This statement is in contradiction with the findings of

Löf and Welander (2000), and Welander and Ottosson (1997) according to whom the leaf area in 2-yr-old beech individuals was solely influenced by the current-year conditions. This contradiction could be explained by the different ontogenetic stages of the investigated plants.

Considering these facts, I hypothesise that the preformation of beech shoots should be reflected also in strength of correlation between the parameters of buds (length, diameter, volume, dry weight) and parameters of shoots sprouted from these buds (e.g. shoot length, dry mass, leaf area and dry mass) in the next year. Quantification of these relations requires inputting values of bud parameters as independent variables. In this context, the objective of my contribution was to evaluate the allometry of buds situated on different parts of shoots, on different types of shoots and in different parts of crowns of naturally regenerating beech trees, and to provide input data for regression models for non-destructive estimation of volume and dry weight of beech buds.

Material and methods

Shoots with winter buds were collected in November/December 2008 in forest stands in three localities situated in central Slovakia: (i) Staré Hory, 48°50'41" N, 19°06'44" E, Veľká Fatra Mts, (ii) Vígľašská Huta-Kalinka, 48°30'13" N, 19°15'06" E, Javorie Mts, and (iii) Jasenie, 48°51'36" N, 19°25'38" E, the Nízke Tatry Mts, all the three at 680–740 m a.s.l. The mean annual temperature at these sites is 6–7 °C (Šťastný et al., 2002), mean annual precipitation total is 700–1,100 mm (Faško and Šťastný, 2002). More details about the localities can be found in Jarčuška (2010) and Jarčuška and Barna (2010).

The shoots were collected from 0.8–1.5 m high individuals, undamaged, without symptoms of attack by pathogens. From each individual, I took the terminal shoot and a long shoot from the upper crown half; and one long and one short shoot from the lower crown part (Table 1; Fig. 1a). From the total number of 48 trees growing in sites differing in solar radiation supply (17 sites, 5–70% of total solar radiation transmitted through the crown canopy), I sampled in summary 258 shoots with more than 840 buds.

Relative amount of accessible solar irradiation was determined based on hemispheric photos captured with fish-eye lens Sigma 4.5 mm F2.8 EX DC (Sigma, Japan) mounted at Canon EOS 400D (Canon, Japan) during summer 2008 and 2009, and analysed by softwares SideLook 1.1 (Nobis, 2005; Nobis and Hunziker, 2005), and Gap Light Analyser 2.0 (Frazer et al., 1999). For more details about hemispherical image analysis, see Jarčuška (2008), and Jarčuška and Barna (2010).

I measured these three dimensions of buds: length, diameter at the base and diameter across the widest part. The measurements were taken with an electronic digital calliper with an accuracy of 0.01 mm (Fig. 1c). Then, the shoots were stored in a fridge (for maximum 7 days). The bud volume (and length repeatedly) were determined with a programme WinRhizo 2004a (Régent Instruments, Canada), performing at an accuracy level of 1.0 mm^3 . The software itself represents standard methods for determining quantitative traits of plant's root system (e.g. Jaloviar et al., 2009). The scanned buds were dried up at a temperature of 80 °C for 48 hours. Finally, the weight (mass) was determined with an accuracy of 0.001 g (Mettler AE 200; Mettler, Switzerland).

The statistical processing of the data was carried out with using only the values of those buds the length of which measured manually by a calliper did not differ from the length measured by WinRhizo by more than 5% – as the storing in the fridge could caused them to shrink ($n = 674$). For the purpose of this study, the buds were divided into seven classes ("bud types"), see Table 1. Allometric relationships between the measured traits of different bud types were determined by using a simple linear regression for fresh bud volume (V) versus bud length (L), maximum diameter (MD),

Table 1. List of 3-cipher codes for "bud type" used in the study

Cipher in the code	Meaning	Code No.	Meaning
1st	Shoot position in crown	1	Upper crown part
		2	Lower crown part
2nd	Shoot type	1	Terminal shoot
		2	1st-order lateral (long) shoot
		3	2nd-order lateral (short) shoot
3rd	Bud position on shoot	1	Terminal bud
		2	Lateral bud (axillary)

basal diameter (BD), and dry weight (W). Log-transformation of the dependent as well as the independent variables was used to obtain their normality and homoscedasticity. Differences among elevations and slopes were tested using a Tukey multiple comparison test (Zar, 1999). The ratios of BD to MD, BD to L, and MD to L reflected in characteristic bud shapes; and the ratio V to W reflected in the bud density ($cm^3 g^{-1}$), were compared by using the main effects anova with factors: "shoot position in crown", "shoot type" and "bud position on shoot". Tukey HSD post-hoc test was computed to determine significant differences between the compared bud types. Response of bud shape and density to the relative amount of total accessible irradiation was assessed by means of Kendall´s Tau correlation.

For the design of the regression model for non-destructive determining of fresh volume and dry weight of buds, I used this independent variable: "volume of cylinder enclosing the bud" (V_{cyl}) with the diameter equal to the bud's maximum diameter and the height equal to the bud's length. After having tested the differences among models for individual bud types, the linear models were parameterised based on randomly chosen portion of data (approx. 90%, uniformly for all bud types). To test whether the resulting models are reasonable, there were validated with the remaining data. Theoretical values of bud volume and weight were calculated from the regression equations (designed models) and then they were regressed against the measured data. Standard t-tests were applied to find out whether the slopes and intercepts of the regression lines differed significantly from unity and zero, respectively. Also the average ratios of the predicted-to-measured values were calculated for values where predicted exceeded measured data, and vice versa. All statistical analyses were performed using Statistica 6.0 (StatSoft, USA).

Results and discussion

Bud allometry

Allometric relationships among bud´s fresh volume (V), its morphological traits (L, MD, BD), and dry weight are strong correlated (adjusted R^2 ranges from 0.45 to 0.99; Table 2). These allometric relationships are mostly dependent on the bud type (bud´s position on shoot, shoot type, shoot position in crown, see Table 1), and they mainly differ in slopes (intercept of V and BD is an exception). In most cases, however, the differences among the buds are not distinct – individual types can be classified into several overlapping homogeneous groups. With increasing bud volume, the highest length growth rate was observed in buds on short shoots in the lower crown halves (code 231), the lowest was the growth rate of terminal buds (codes 111, 112). The bud type had no influence on relation between the bud volume and its maximal diameter (Table 2). MD (among morphological traits) provided the best estimation of bud volume. Relationship between V and basal diameter was less strong in comparison with the other evaluated traits. Cochard et al. (2005) found that the area of

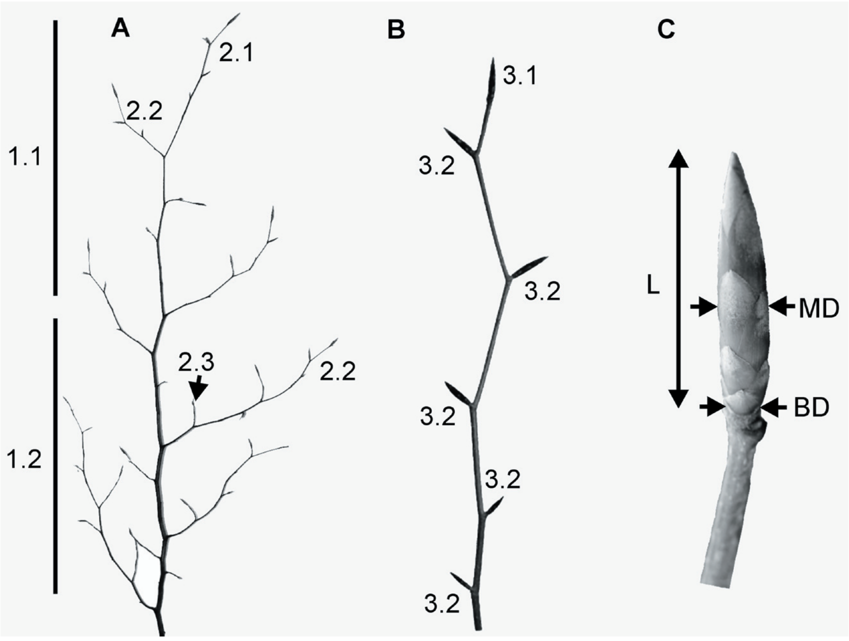


Fig. 1. Schematic representation of a seedling (A) and shoot (B), position of shoot samplingspots in the crown (1.1 , 1.2), shoot type (2.1 , 2.2 , 2.3) and types of buds on shoots (3.1, 3.2). The first cipher means the order in the code ‚bud type'; the second denotes the value itself of the number in the code (Code No.; see Table 1). (C) Measured variables of bud: (L) length, (MD) maximum maximal diameter, and (BD) basal diameter

a shoot annual ring was correlated with hydraulic conductance of xylem, and that high xylem conductance was associated with the occurrence of a large number of leaf primordia in buds. Consequently, we may expect a significant correlation between BD and characteristics of biomass sprouted from these buds. Dry weight of buds from the upper crown part correlated with their volume stronger than in case of buds from the lower crown (R^2_{adj} = 0.99 and 0.94–0.97, respectively; Table 2). A possible explanation is in lower accessibility and bigger variability of light in lower crown parts (cf. Petritan et al., 2009). Cochard et al. (2005) reports an example of buds on lower branches of mature beech trees manifesting a high correlation between the fresh mass of buds and dry mass of leaf primordia (R^2 = 0.94), and also with the number of leaf primordia in the bud (R^2 = 0.91).

Bud type (Table 1) had an important influence on bud shape characterised by the ratios of BD to MD, and BD to L, with factor "bud position on shoot" manifesting a stronger effect (Table 3). The highest values of BD/MD were observed in lateral buds on long (terminal

Table 2. Linear models for regression lines describing dependence of bud volume (*x*) on bud length, maximum diameter, base diameter and weight (*y*). The regression equation is $(\log)y = a + b(\log)x$. All regressions were found statistically significant ($p < 0.001$). The values of intercepts and slopes were divided into homogeneous groups based on the results of the Tukey multiple comparison test (Zar, 1999) at a 0.05 significance level. Bud type abbreviations are in Table 1 (L) denotes bud length, (MD) maximum diameter, (BD) basal diameter, (W) dry weight of bud, (V) bud fresh volume, (R^2_{adj}) adjusted R^2.

y	Bud type	*n*	Intercept (*a*)		Slope (*b*)		R^2_{adj}
L	111	40	0.6841	*a*	0.3176	*ab*	0.89
	112	166	0.7060	*a*	0.3053	*a*	0.91
	121	72	0.6706	*a*	0.3262	*ab*	0.89
	122	204	0.6431	*a*	0.3464	*bc*	0.90
	221	55	0.6092	*a*	0.3776	*bc*	0.80
	222	81	0.6295	*a*	0.3617	*abc*	0.82
	231	56	0.5652	*a*	0.4138	*c*	0.84
MD	111	40	–0.2094	*a*	0.3551	*a*	0.95
	112	166	–0.1543	*a*	0.3240	*a*	0.95
	121	72	–0.1912	*a*	0.3451	*a*	0.95
	122	204	–0.1651	*a*	0.3298	*a*	0.93
	221	55	–0.1567	*a*	0.3244	*a*	0.81
	222	81	–0.1543	*a*	0.3180	*a*	0.72
	231	56	–0.1380	*a*	0.3024	*a*	0.81
BD	111	40	–0.3562	*abc*	0.3570	*a*	0.79
	112	166	–0.1737	*a*	0.2691	*b*	0.84
	121	72	–0.2827	*bc*	0.3179	*ab*	0.82
	122	204	–0.2106	*c*	0.2823	*ab*	0.81
	221	55	–0.2121	*b*	0.2494	*ab*	0.45
	222	81	–0.2056	*b*	0.2538	*ab*	0.55
	231	56	–0.2287	*b*	0.2633	*ab*	0.67
W	111	40	–3.1330	*a*	0.9686	*ab*	0.99
	112	166	–3.1657	*a*	0.9810	*b*	0.99
	121	72	–3.1921	*a*	0.9985	*ab*	0.99
	122	204	–3.1896	*a*	0.9975	*ab*	0.97
	221	55	–3.2617	*a*	1.0535	*a*	0.97
	222	81	–3.1880	*a*	0.9889	*ab*	0.94
	231	56	–3.2262	*a*	1.0199	*ab*	0.95

and lateral) shoots in the upper crown halves (Table 4). Neither MD/L nor bud density (V/W; cm^3 g^{-1}) depended on the bud type.

Accessible light had negative influence on BD/L and MD/L in lateral buds on long shoots in upper crown halves (code 122); on the other hand, in case of buds on long shoots in lower crown part (222), this influence was positive. With increasing light supply decreased bud density on short shoots (231), that means that their volume increased faster than their dry weight (Kendall $\tau = 0.26$, $p < 0.01$; Table 5).

Strong correlation between morphometric parameters of buds and their dry weight with bud volume provides a sound background for designing models for non-destructive determination of volume and dry weight of all the buds involved in interest.

Design and testing of a model for estimation of bud fresh volume and dry weight

Because there were no significant differences between bud types defined by comparing regression equations expressing dependence of volume and of bud's dry weight on the volume of the bud-enclosing cylinder (V_{cyl}; Table 6), I have created models for estimation of V and W that did not depend on the bud type. In these models, V_{cyl} (independent variable) accounted for 98% of variation in bud volume and also in bud dry weight **(**Table 7). Relative accuracy of prediction at a 95% significance level was 6.4% for bud fresh volume, and 5.4% for bud dry weight. For example, the determination coefficient value for relationship between leaf area and rectangle length × width obtained by Masarovičová and Požgaj

Table 3. Influence of shoot position in crown, shoot type and bud position on shoot on bud morphology (ratios of BD/MD, BD/L, MD/L) and bud density (V/W). Outputs from anova. (L) denote: bud length, (MD) maximum diameter, (BD) basal diameter, (W) dry weight of bud, and (V) bud fresh volume

	Shoot position in crown		Shoot type		Bud position on shoot	
	F	*P*	*F*	*P*	*F*	*P*
BD/MD	8.38	**0.0039**	5.55	**0.0041**	66.15	**0.0000**
BD/L	3.01	0.0832	4.08	**0.0174**	22.74	**0.0000**
MD/L	0.02	0.9021	0.63	0.5311	0.13	0.7175
V/W	0.69	0.4067	1.02	0.3616	0.73	0.3921

Table 4. Trait ratios mean and SE (in brackets) comparison tests between bud types of beech natural regeneration individuals. Means from a given line followed by the same letter are not significantly different at the 5% threshold based on Tukey HSD post-hoc test. Bud type abbreviations are given in Table 1. For trait ratios abbreviations see Table 3.

	Bud type						
	111 (*n* = 40)	112 (*n* = 166)	121 (*n* = 72)	122 (*n* = 204)	221 (*n* = 55)	222 (*n* = 81)	231 (*n* = 56)
BG/MG	0.726 (0.001) *ab*	0.792 (0.005) *d*	0.732 (0.008) *ab*	0.777 (0.005) *cd*	0.707 (0.009) *a*	0.757 (0.008) *bc*	0.739 (0.009) *abc*
BG/L	0.110 (0.003) *abc*	0.117 (0.001) *c*	0.108 (0.002) *ab*	0.115 (0.001) *bc*	0.105 (0.002) *a*	0.113 (0.002) *abc*	0.112 (0.002) *abc*
MG/L	0.151 (0.003) *a*	0.148 (0.001) *a*	0.149 (0.002) *a*	0.148 (0.001) *a*	0.148 (0.003) *a*	0.149 (0.002) *a*	0.152 (0.002) *a*
V/W [cm^3 g^{-1}]	1.560 (0.025) *a*	1.571 (0.012) *a*	1.570 (0.019) *a*	1.570 (0.011) *a*	1.563 (0.021) *a*	1.596 (0.018) *a*	1.613 (0.021) *a*

Table 5. Relationship between relative amount of accessible total irradiation versus bud shape (BD/MD, BD/L, MD/L) and bud density (V/W). Kendall´s rank correlation coefficients (τ) are shown with the significance levels (not significant are not in bold, * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$). Bud type abbreviations are given in Table 1. For trait ratios abbreviations see Table 3.

Bud type	BD/MD	BD/L	MD/L	V/W
111	–0.02	0.12	0.16	–0.05
112	0.09	–0.01	–0.09	–0.00
121	0.09	0.02	–0.08	0.02
122	–0.02	**–0.12***	**–0.16*****	0.02
221	0.11	**0.31*****	**0.38*****	–0.13
222	0.01	**0.18***	**0.19***	–0.06
231	0.05	–0.06	–0.08	**0.26****

(1988) in their comparative analysis of leaf area in three oak species ranged 0.79–0.98. Cicák (2003, 2008), applying his method of calculation coefficients for estimation of morphological parameters and dry weight on European beech leaves on spring shoots, obtained for response of calculation coefficient values to the leaf number on a shoot a value R^2 ranging 0.88–0.97.

I tested these models with an independent set of buds (n = 62). They could explain 98% and 99% of variation in the measured bud volume and dry weight, respectively (Fig. 2). Intercepts and slopes of these relationships were not significantly different from zero and one, respectively P for V: $P_{\text{intercept}} = 0.67$, $P_{\text{slope}} = 0.67$, and for W: $P_{\text{intercept}} = 0.99$, $P_{\text{slope}} = 0.48$). The average ratios of predicted-to-measured values were both close to unity (1.05, 1.02 for V and W, respectively). For the two variables, more than 60% of the predicted values were higher than the measured values (Table 8). The average ratio for the group with predicted > measured values as well as the group with measured > predicted values was lower for dry weight of buds than for bud's volume. The values scattering along the $y = x$ line respond the differences between the predicted and measured values of the evaluated variables associated with different bud response in fresh volume and dry mass to the volume of bud-enclosing cylinder V_{cyl} (Table 6) and also associated with the variability within the individual bud types.

The proposed methods for non-destructive estimation of fresh volume and dry weight of winter buds in beech natural regeneration are based on easily measurable morphological parameters, and perform with a high accuracy and out of dependence on the type of bud and amount of light supply.

Table 6. Linear models for regression lines explaining the dependence of volume of cylinder enclosing the bud V_{cyl} (diameter of cylinder equal to the maximum bud's diameter, height equal to the bud's length) (x) on the bud's volume and dry weight (y) for individual bud types. The regression equation is $(\log)y = a + b(\log)x$. All regressions were statistically significant ($P < 0.001$). The values of intercepts and slopes have been divided into homogeneous groups based of the results of the Tukey multiple comparison test (Zar, 1999) at 0.05 significance level Abbreviations for bud type are given in Table 1. (W) denotes dry weight of bud, (V) bud's volume, (R^2_{adj}) adjusted R^2.

y	Bud type	*n*	Intercept (*a*)		Slope (*b*)		R^2_{adj}
V	111	40	–0.1306	*a*	0.9611	*abc*	0.98
	112	166	–0.2623	*a*	1.0227	*c*	0.98
	121	72	–0.1311	*a*	0.9581	*abc*	0.97
	122	204	–0.1776	*a*	0.9771	*abc*	0.98
	221	55	–0.0930	*a*	0.9134	*a*	0.94
	222	81	–0.0727	*a*	0.8933	*ab*	0.89
	231	56	–0.1051	*a*	0.9221	*abc*	0.94
W	111	40	–3.2762	*a*	0.9389	*a*	0.99
	112	166	–3.4378	*a*	1.0116	*c*	0.99
	121	72	–3.3423	*a*	0.9668	*abc*	0.98
	122	204	–3.3839	*a*	0.9853	*abc*	0.97
	221	55	–3.3931	*a*	0.9841	*abc*	0.95
	222	81	–3.3190	*a*	0.9282	*ab*	0.93
	231	56	–3.3640	*a*	0.9645	*abc*	0.94

Table 7. Results of linear regression analysis on bud fresh volume, and dry weight of European beech (*Fagus sylvatica* L.) natural regeneration (saplings) with the volume of cylinder enclosing the bud (V_{cyl}) as an independent variable (n = 610). Regression coefficients (standard error in brackets) and adjusted percentage of variation explained (R^2_{adj}) are presented. The regression equation is $(\log)y = a + (\log)bx$. All regressions were found statistically significant ($P < 0.0001$).

Model	Intercept	Slope	Syx	R^2_{adj}
Volume	–0.239749 (0.008072)	0.981349 (0.005700)	0.05033	0.980
Weight	–0.422385 (0.007705)	0.991274 (0.005440)	0.04804	0.982

Table 8. Average ratio of the predicted-to-measured values (of bud's volume and dry weight) where the predicted value exceeded measured (P > M), and vice versa (M > P; standard error in brackets)

	P > M		M > P	
	Ratio	%	Ratio	%
Volume	1.11 (0.02)	61	1.07 (0.01)	39
Weight	1.07 (0.01)	65	1.07 (0.01)	35

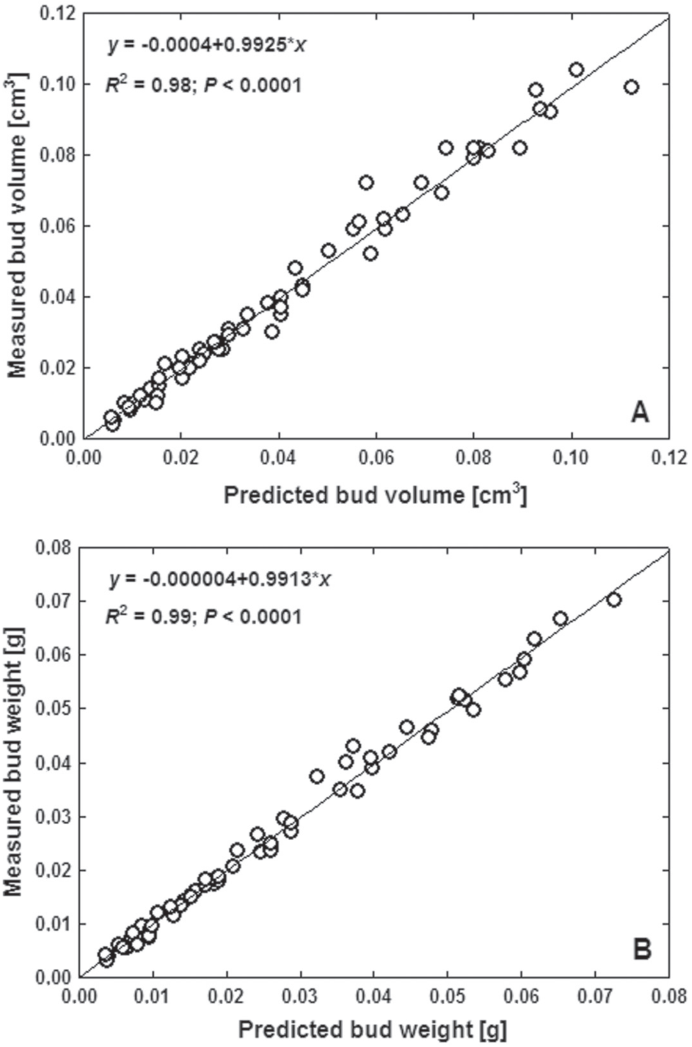


Fig. 2. Relationship between predicted and measured bud fresh volume (A), and dry weight (B) of beech natural regeneration saplings (n = 62). Predicted values were calculated based on regression equations listed in Table 7. The regression equation is of the form y = a + bx. Intercepts were not significantly different from zero and slopes were not significantly different from unity.

Acknowledgement

I am thankful to Peter Jaloviar, Faculty of Forestry, Technical University in Zvolen, for the access to the software WinRhizo, and to Dagmar Kúdelová for the help with preparing the English text. This study was financially supported by the grant VEGA No. 2/0055/10.

References

Barthélémy, D., Caraglio, Y. 2007. Plant architecture: a dynamic, multilevel and comprehensive approach to plant form, structure and ontogeny. *Ann. Bot.*, 99: 357–407.

Cicák, A. 2003. Estimation of morphological parameters for European beech leaves on spring shoots using the method of calculation coefficients. *Folia oecol*., 30: 131–140.

Cicák, A. 2008. *Stanovenia suchej hmotnosti listov jarných výhonkov buka lesného metódou prepočtových koeficientov* [Estimation of dry weight for European beech leaves on spring shoots using the method of calculation coefficients]. E-ekológia lesa: odborné ekologické publikácie, No. 8. Zvolen: Ústav ekológie lesa SAV. 9 p. [cit. 2009-07-15]. <http://www.savzv.sk/domain/b6/files/e-ekologia-lesa/e_ekol_no6_2008.pdf >

Cochard, H., Coste, S., Chanson, B., Guehl, J.M., Nicolini, E. 2005. Hydraulic architecture correlates with bud organogenesis and primary shoot growth in beech (Fagus sylvatica). *Tree Physiol*., 25: 1545–1552.

Eschrich, W., Burchardt, R., Essiamah, S. 1989. The induction of sun and shade leaves of the European beech (Fagus sylvatica L.): anatomical studies. *Trees*, 3: 1–10.

Faško, P., Šťastný, P. 2002. Priemerné ročné úhrny zrážok: Mean annual precipitation totals. In Miklós, L., Maráky, P., Klinda, J. et al. (eds.). *Atlas krajiny Slovenskej republiky: Landscape atlas of the Slovak Republic.* Bratislava: Ministerstvo životného prostredia SR, p. 99.

Frazer, G.W., Canham, C.D., Lertzman, K.P. 1999. *Gap light analyzer (GLA). Version 2.0. Imaging software to extract canopy structure and gap light transmission indices from true-color fisheye potographs: users' manual and program documentation*. Burnaby: Simon Fraser University. 36 p.

Nobis, M., 2005. *SideLook 1.1 – Imaging software for the analysis of vegetation structure with true-colour photographs.* 6 p. [cit. 2008-03-31]. <www.appleco.ch>

Nobis, M., Hunziker, U., 2005. Automatic thresholding for hemispherical canopyphotographs based on edge detection. *Agric. For. Meteorol*., 128: 243–250.

Jaloviar, P., Bakošová, L., Vencurik, J., Kucbel, S. 2009. Quantity and distribution of fine root biomass in the intermediate stage of beech virgin forest Badínsky prales. *J. Forest Sci*., 55: 502–510.

Jarčuška, B. 2008. Methodical overview to hemispherical photography, demonstrated on an example of the software GLA. *Folia oecol*., 35: 66–69.

Jarčuška, B. 2010. Morphological plasticity of beech (*Fagus sylvatica* L.) leaves on spring shoots in natural regeneration: direct and diffuse light, ontogeny and shoot type. *Pol. J. Ecol*. (in press).

Jarčuška, B., Barna, M. 2010. Influence of light availability on height growth of beech (Fagus sylvatica L.) natural regeneration with different growth history. (in preparation).

Löf, M., Welander, N.T. 2000. Carry-over effects on growth and transpiration in Fagus sylvatica seedlings after drought at various stages of development. *Can. J. Forest Res*., 30: 468–475.

Masarovičová, E. 1985. Growth activity of the various growing phase shoots in the European beech trees (Fagus sylvatica L.). *Acta Univ. agric. (Brno), řada A*., 33: 637–642.

Masarovičová, E., Požgaj, J. 1988. Comparative analysis of the leaf area in three oak species- a methodical contribution. *Biológia (Bratislava)*, 43: 449–457.

Petritan, A.M., von Lüpke, B., Petritan, I.C. 2009. Influence of light availability on growth, leaf morphology and plant architecture of beech (Fagus sylvatica L.), maple (Acer pseudopla*tanus* L.) and ash (Fraxinus excelsior L.) saplings. *Eur. J. Forest Res*., 128: 61–74.

Roloff, A., 1987. Morfologie der Kronenetwicklung von Fagus sylvatica L. (Rotbuche) unter besonderer Berücksichtigung neuartiger Veränderungen. I. Morphogenetischen Zyklus, Anomalien infolge Prolepsys und Blattfall. *Flora*, 179: 355–378.

Šťastný, P., Nieplová, E., Melo, M. 2002. Priemerná ročná teplota vzduchu: Mean annual air temperature. In Miklós, L., Maráky, P., Klinda, J. et al. (eds.). *Atlas krajiny Slovenskej republiky: Landscape atlas of the Slovak Republic*. Bratislava: Ministerstvo životného prostredia SR. p. 98.

Welander, N.T., Ottosson, B. 1997. Influence of photosynthetic photon flux density on growth and transpiration in seedlings of Fagus sylvatica. *Tree Physiol*., 17: 133–140.

Zar, J.H. 1999. *Biostatistical analysis*. New Jersey: Prentice Hall. 663 p.

Alometria na úrovni zimných púčikov prirodzeného zmladenia buka *Fagus sylvatica* L.) s ohľadom na stanovenie ich objemu a suchej hmotnosti

Súhrn

Primordiá jarných výhonkov buka lesného (*Fagus sylvatica* L.) sú vytvorené v púčiku už v predchádzajúcom vegetačnom období. Preto možno predpokladať, že sa tento proces odrazí v sile korelácie medzi charakteristikami púčikov – dĺžka (L), maximálny priemer (MD), priemer na báze (BD), čerstvým objem púčika (V) a hmotnosťou sušiny (W) a charakteristikami z nich vypučaných výhonkov (napr. dĺžka výhonku, jeho hmotnosť, listová plocha, váha sušiny). Kvantifikovanie týchto vzťahov si vyžaduje nedeštruktívne stanovenie hodnôt nezávislých premenných. Cieľom tohto príspevku je preto na základe zhodnotenia alometrie púčikov nárastu buka vytvoriť regresné modely umožňujúce stanovenie V a W púčikov buka.

Alometrické vzťahy medzi V púčika nárastu buka a jeho L, MD, BD a W sú vzájomne silno korelované. Tieto vzťahy zväčša závisia od typu púčika charakterizovaného jeho polohou na výhonku, typu daného výhonku a umiestnenia výhonku v korune. Vo väčšine prípadov však rozdiely medzi jednotlivými typmi púčikov nie sú jasne odlíšiteľné – jednotlivé typy sú zaradené do viacerých vzájomne sa prekrývajúcich homogénnych skupín. Typ púčika vplýva významne na tvar púčika charakterizovaný pomermi BD ku MD a BD ku L, nevplýva na pomer MD/L a špecifickú hmotnosť púčika (V/W). Vplyv dostupného svetla na tvar a špecifickú hmotnosť púčika závisí taktiež od jeho typu.

Na nedeštrukčné stanovenie V a W boli vytvorené lineárne regresné modely s charakteristikou ‚objem valca opísaného púčiku' (V_{cyl}) použitou ako nezávislou premennou. Tento model s relatívnou presnosťou 6,4 % pre V a 5,4 % pre W ($P = 0{,}95$) vysvetľoval 98 % variability V a W púčikov zmladenia buka. Test vytvoreného modelu na nezávislom súbore dát potvrdil, že jeho použitie prináša výsledky porovnateľné s priamym meraním zisťovaných charakteristík.

Received January 26, 2010
Accepted May 6, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Evaluation of ground level ozone concentrations and climatic variables in submountain beech forests (Western Carpathians Mts)

Daniela Kellerová, Rastislav Janík

Institute of Forest Ecology, Slovak Academy of Sciences, Štúrova 2, 960 53 Zvolen, Slovak Republic,
E-mail: kellerova@savzv.sk, janik@savzv.sk

Abstract

KELLEROVÁ, D., JANÍK, R. 2010. Evaluation of ground level ozone concentrations and climatic variables in submountain beech forests (Western Carpathians Mts). *Folia oecol.*, 37: 51–54.

Research, carried out in submoutain beech stand in the Kremnické vrchy Mts (410–570 m a.s.l.), was used to determine differences in ground level ozone concentrations and values of selected climatic variables between a former clear-cut which was the result from a cutting performed in 1989 and also a beech forest stand not subjected to the intervention. Differences in ozone concentrations were pronounced mainly in summer (July, August) when the values on the former clear-cut were much higher than those measured in the forest stand. In August 2004, a value of 118 μg m^{-3} was recorded on the former clear-cut. The increase in air temperature in the region was up to 15.4 °C, compared to the former long term mean value 14.8 °C from years 1961–1990 which was reported from Sliač, this is unequivocal.

Key words

air temperature, ground level ozone, illumination intensity, precipitation, submountain beech

Introduction

Forests covering 40% of Slovak territory are subjected to significant changes, including changes to the local climate – initiated due to both anthropogenic and natural influence. Over the past decades, many various changes were characteristic for the whole of Central Europe (ALEWELL et al., 2000). These changes were mainly connected with conversion and innovation of industry, and with measures accepted in legislation. The positive turn over in trends in emmissions and airborne pollutants was mainly thanks to a considerable decrease in pollutants of domestic origin (SPIŠÁKOVÁ et al., 2003). The present pollution is caused by particular matter and by ozone (VÁŇA and SMRČKOVÁ, 2000; SHMÚ, 2006). This development shows a positive trend, nevertheless the decrease in NO_x – one of ozone precursors was not as steep as that of the SO_2 emissions (FLEISCHER et. al., 2005). Periods of dry warm weather represent unfavourable climatic conditions promoting an increase in the amount of ground level ozone consequently, creating an adverse effect on public health, vegetation and whole ecosystems (BIČÁROVÁ et al., 2005; GODZIK and GRODZINSKA, 2002; ŠEC et. al., 2007). Ozone is a photo-chemical pollutant arising from the presence of precursors: nitrogen oxides and VOC, coupled with the presence of favourable photo-chemically favourable conditions. This substance initiates changes to plant assimilatory organs which slows down photosynthesis and influences synthesis of chlorophyll. In spite of the ecological measures applied, the ozone concentrations reach beyond the limit values (ŠACH and ČERNOHOUS, 2005; ZAPLETAL and CHROUST, 2007). Based on the measurements made by the EMEP network stations, Slovakia has been classified as a country with a medium ozone load. The most severely loaded are industrial European areas such as: Germany, France, and Mediterranean area: Italy, Spain (ELVINGSON and ÅRGEN, 2004). At present, the influence of ozone load is higher in the countryside and mountainous areas rather than urban areas. For this reason, our research was focussed on pollution of the ground layer of atmosphere in an area of forest type which was sufficiently more remote from urban and local pollution sources. Amounts and characteristicts of pollutants at local and regional levels are determined by a range of factors – acting in synergy – the origin of which can be meteorological, organic or caused by precursors. Recognition of causes and regularities in performance of individual climatic factors should help to maintain the necessary equilibrium between all components of ecosystems, humans not omitted.

Material and methods

The purpose of our research was to determine differences in ground level ozone concentrations and values of selected climatic variables between the ones entering a forest stand and those entering a plot which was subjected in 1989 as clear cutting – this resulted in a stocking density of 0.0. At the moment of cutting intervention, the stand age was 80–90 years. The stand without intervention is dominated by beech, covering 94.7% of the stand area. The research subjects are situated in Central Slovakia, in the SE part of the Kremnické vrchy Mts (Western Carpathians Mts, $\varphi = 48°38'$ N, $\lambda = 19°04'$ E), at an altitude of 470–510 m. The slope is exposed on the west, with an inclination of 30–36%. For measuring the long-term influence of immission load to forest ecosystems a suitable method to determine the ground level ozone (O_3) concentrations would by provided with the sorption-accumulation method (WERNER, 1991). The values of ground level ozone concentration, air and soil temperature and precipitation amounts were recorded at regular intervals covering the whole growing seasons. Illumination intensity was measured at the time without leaves and at the time of leaves fully developed.

Results and discussion

The values of ozone concentrations obtained by passive sampling were analysed. The research started 10 years after the cutting. The stand left without intervention has maintained its original characteristicts – without understorey. The dynamical regeneration running on the former clear-cut has resulted in the current 16-year-old young growth with dominant beech. The description of the two different plots together with mean ozone concentration values and other important parameters are outlined in Table 1. In spring, in the absence of sufficient foliage with an air temperature reaching minima on both plots, the values of ozone concentrations were very similar. The differences in ozone concentrations between the plots were especially marked in summer (July, August) – reaching on the former clear-cut much higher values than in the forest stand: Figs 1 A and B. Such big differences could mainly follow from extremely high ozone concentrations: in August 2004 we recorded on the former clear-cut a value of 118 $\mu g\ m^{-3}$. The mean ozone concentration of 40 $\mu g\ m^{-3}$ obtained in years 1999–2003 increased in the following years 2004–2006 to 55 $\mu g\ m^{-3}$. The mean temperature value in 1999–2003 on both 15.35 °C, in the following years 2004–2006 it was 15.45 °C. Comparing these values with the long term mean from Sliač – representing 14.8 °C for years 1961–1990, the increase in air temperature in this region is undisputable.

Conclusions

In terms of ecological stability, the area of the Kremnické vrchy Mts has previously been considered as only slightly polluted. In spite of this classification, also in this area occur episodes with high ozone concentrations (118 $\mu g\ m^{-3}$). Increasing air temperature and ozone concentrations seem to be risk factors in this sub-mountain

Table 1. Dynamics of natural and artificial regeneration of a small-sized clear-cut, history of stocking density in a beech stand in the Kremnické vrchy Mts, mean air temperature, precipitation, illumination intensity and mean values of ground level ozone during vegetation periods

Research plots	Clear cut	Forest stand without intervention
1989 cutting intervention	0.0 density	0.9 density
1999 10 years after cutting	Young growth	0.9 density
2004 15 years after cutting	Small pole stage	1.0 density
1999–2006 mean temperature	15.6 °C	15.3 °C
1999–2006 precipitation	678 mm	511 mm
1999–2006 mean O_3 concentration	49 $\mu g\ m^{-3}$	46 $\mu g\ m^{-3}$
Illumination intensity		
Before foliage 1990	36 klx	15.7 klx
Before foliage 2001	6.7 klx	6.7 klx
Under foliage 1990	40.9 klx	2.5 klx
Under foliage 2001	0.6 klx	1.2 klx

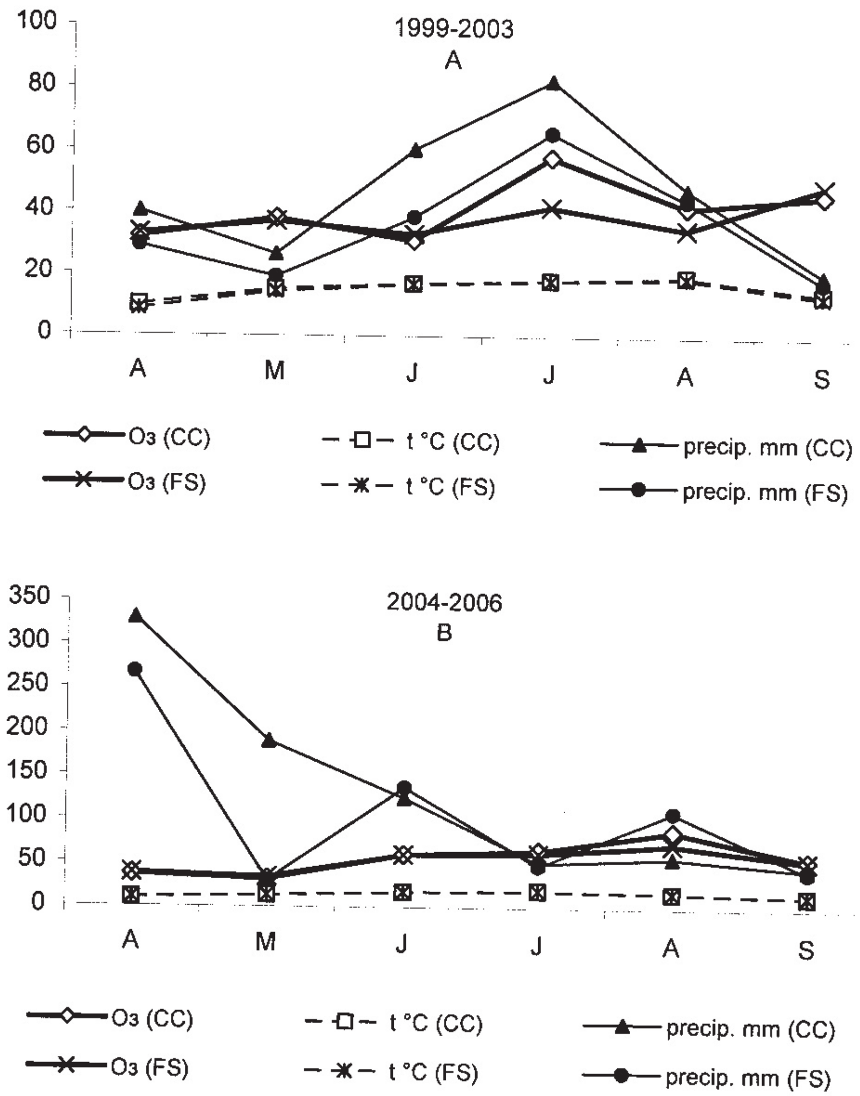


Fig 1. History of air temperature, precipitation and ozone concentrations (warm half-of-year) on a former clear-cut (CC) and in a forest stand (FS) not subjected to cutting intervention situated in submoutain beech in the Kremnické vrchy Mts: A – 10 years after cutting, B – 15 years after cutting, (O_3 concentration: µg m^{-3})

area, in spite of the fact that they do not reach extreme values reported from other regions of Slovakia. Conditions necessary for ozone creation are dependent on developing meteorological situations and the maintenance of extensive areas during anticyclones.

Acknowledgement

This work was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and Slovak Academy of Sciences (Projects No. 2/0034/10, 2/0055/10, 2/0068/10, 2/0045/08). We also acknowledge D. Kúdelová for preparing the English text.

References

Alewell, CH., Manderscheid, B., Gersberger, P., Matzner, E. 2000. Effects of reduced atmospheric deposition on soil solution chemistry and elemental contens of spruce needles in NE-Bavaria, Germany. *J. Pl. Nutr. Soil Sci.,* 163: 509–516.

Bičárová, S., Sojáková, M., Fleischer, P. 2005. Summer ground level ozone maximum in Slovakia in 2003. *Contr. Geophys. and Geod.,* 35/3: 265–279.

Elvingson, P., Årgen, Ch. 2004. *Air and the environment*, Göteborg: Department of Applied Environmental Science. 174 p.

Fleischer, P., Godzik, B., Bičárová, S., Bytnerowicz, A. 2005. Effects of air pollution and climate change of forests of Tatra Mountains, Central Europe. In *Plant responses to air pollution and global change*. Tokyo: Springer-Verlag Tokyo, p. 111–121.

Godzik, B., Grodzinska, K. 2002. Ground level ozone concentration and effect on plants Polish NP. *KOSMOS*, 51/4: 427–434.

Shmú, odb. kvality ovzdušia. 2006. *Hodnotenie kvality ovzdušia v Slovenskej republike 2005* [Evaluation of air quality in SR in 2005]. Bratislava. Slovenský hydrometeorologický ústav. 72 p.

Spišáková, K., Sajtáková, E., Závodský, D. 2003. Emission of air pollutions in the Slovak Republic. *Meteorol. Čas.*, 6: 11–15.

Šach, F., Černohous, V. 2005. Ground-level ozone and potential infuence on declining experimental Norway spruce plantation in immission region of the Orlické vrchy Mts., Czech Republic. In Saniga, M., Jaloviar, P. (eds). *Súčasné otázky pestovania lesa. Zborník zo VII. česko-slovenského vedeckého sympózia vedecko-pedagagogických a vedecko-výskumných pracovísk v odbore Pestovania lesa, Zvolen, 6.9.–7.9. 2005*. Zvolen: Technická univerzita, p. 101–106.

Šec, K., Skácel, F., Malec, L., Tekáč, V. 2007. Studium faktorů ovlyvňujících vznik a zánik troposférického ozónu [Study of factors initiating the origin and extinction of tropospheric ozone]. *Chem. Listy*, 101: 1051–1057.

Váňa, M., Smrčková V. 2000. Surface ozone at the GAW and EMEP stations in the Czech Republic. *Meteorol. Čas.*, 3: 9–18.

Zapletal, M., Chroust, P. 2007. Depoziční tok ozonu do lesních ekosystémů na území ČR. Deposition flow of ozone into forest ecosystems across the Czech Republic territory. *Ochr. Ovzduší*, 3: 20–26.

Werner, H. 1991. Methodische Details für das Ozonmonitoring mit Indigopapieren. In Weissgerber, K., Biebl, P., Brandtner, B., Puxbaum, H. *II. Workshop zum Thema Integrale Messmethoden. Workshopbericht der Unterarbeitsgruppe Integrale Messmethoden im Rahmen von ARGE ALP und ARGE Alpen-Adria* [Workshop on the Integral Measurement Methods. Report of the Working Group Integral Measurement Methods in frame of ARGE ALP and ARGE Alpen-Adria]. Salzburg: Salzburger Landesregierung. 110 p.

Hodnotenie meraní koncentrácií prízemného ozónu a klimatických faktorov v podhorských bučinách (Západné Karpaty)

Súhrn

Zámerom výskumu v podmienkach podhorských bučín v Kremnických vrchoch (410–570 m a. s. l.) bolo zistiť diferencie v koncentrácii prízemného ozónu a klimatických faktorov na pôvodnej holine, ktorá vznikla ťažbou stromov v roku 1989 a v bukovom poraste bez ťažbového zásahu. Diferencie sa ukázali najmä v letných mesiacoch júl a august, kedy boli na pôvodnej holine v porovnaní s porastom najvyššie koncentrácie ozónu. V auguste 2004 bola na pôvodnej holine nameraná hodnota 118 µg m^{-3}. Nárast teplôt vzduchu na 15,4 °C v regióne je v porovnaní s dlhodobým priemerom 14,8 °C z rokov 1961–1990 zo Sliača jednoznačný. Priemerná teplota 15,6 °C na pôvodnej holine bola vyššia ako 15,3 °C v poraste, podobne aj zrážok (678 mm) tu bolo za rovnaké obdobie zachytených viac ako v poraste (511 mm).

Received October 28, 2009
Accepted December 18, 2009

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Oxidative stress symptoms in Norway spruce needles (*Picea abies* L. Karst.)

Václav Krpeš

Department of Biology and Ecology, Faculty of Science, University of Ostrava, ul. 30. dubna 22, 701 03 Ostrava, Czech Republic, E-mail: vaclav.krpes@osu.cz

Abstract

Krpeš, V. 2010. Oxidative stress symptoms in Norway spruce needles (*Picea abies* L. Karst.). *Folia oecol*., 37: 55–60.

We observed the deformation level in mesophyll cells in Norway spruce (*Picea abies* L. Karst.) needles displaying characteristic features of ozone damage. There were examined mesophyll cells under discoloured spots (zones) in epidermis and hypodermis. We evaluated modifications in their water potential as well as relative occurrence of healthy and damaged cells, and determined relation between healthy and diseased mesophyll cells expressed by the cell shape index indicating the degree of the damage.

Key words

cell shape index, Norway spruce (*Picea abies* L. Karst*)*, mesophyll, reactive forms of oxygen

Introduction

The spruce stands in middle altitudes are often exposed to harmful influence of both biotic and abiotic factors. These factors cause stress, activated mainly by the reactive forms of oxygen. Molecular oxygen and its radical derivatives, which are initiated mainly by photochemical reactions in presence of excessive amount of UV radiation, may lead to photooxidation of photosynthetical pigments, particularly chlorophyll *a* (Bergendi, 1988). Hydrogen dioxide, when present in chloroplasts even in small concentrations, inhibits the CO_2 fixation. This results in disruption of oxidation-reduction balance of cells and oxidation damage to cell components (Mangel and Ziegler, 1986; Oswald and Elstner, 1986; Hippeli and Elstner, 1997). The cell water potential reduction and its deformation is very common. Plants have developed a defensive anti-oxidation system against the above mentioned oxidative damage. This system consists of an enzyme complex including for instance ascorbatperoxidaze, superoxiddismutaze, catalaze, and a non-enzymatic part containing a zeaxantine, α-toco-ferol, β-carotene, ascorbat. Anti-oxidative defence activation influences the plant's vulnerability and tolerance to stress in plants (Piterkova et al., 2005; Purvis et al., 1995; Dotzler et al., 1990). The defence of enzymes occurs in several isoforms. The amount of cytokinins in general decreases under unfavourable conditions, and certain phytohormones become important for defensive response to stress. In the damaged one-year-old needles of the studied Norway spruce growing in the 7th and 8th forest vegetation zones were found different levels of cell deformations, changes in their water potential, and in relative frequency of healthy and damaged cells.

Our research objectives were:

- To determine the extent of deformation of mesophyll cells of Norway spruce (*Picea abies* L. Karst.) below epidermal and hypodermal decolorized zones in the damaged Norway spruce needles
- To measure the ratio of damaged to undamaged cells, and to determine a shape index for damage to the studied needle segments
- To determine level of deformation for damaged cells and differences in their water potential.

Material and methods

Plant material

One-year-old needles of damaged spruce trees (*Picea abies* L. Karst.). Their characteristic feature was discolouration in form of visible rounded yellow spots 1–2 mm in diameter (Fig. 1).

Locality

Lysá hora, the Moravskoslezské Beskydy Mts, peak part, 8th vegetation zone, forest type 8Z2 – peak bilberry rowan pine grove (Sorbeto Piceetum), altitude 1,310 m above the sea level. A severely damaged adult pine stand, main soil types: ranker, podzol and cryptopodzol with raw humus, very acidic, clay-sand soil, skeletal to boulder, fresh moisture.

Fig. 1. One-year-old needles of Norway spruce with characteristic symptoms of ozone-caused damage. There are hyaline or yellow chlorosis spots visible on the needles. Locality: Lysá hora, 1,310 m above the sea level

Histology

Sampling of one-year-old needles, year-class 2007, was carried out on 14. 5. 2008 at 14.30. The samples were fixed with a FAA (formalin aceto-alcohol) fixation solution. They were blocked, particular damaged segments were cut, separated, and processed by application of histopathological and histochemical methods. They were embedded Bio-Plastic (at the temperature of 58 °C) and paraffin blocks were cut off with a rotary microtome HM 325, MICROM GmbH (Germany). The thickness of the slices was – if possible – from 4 to 7 µm. We used with advantage silanised glass and a special Superfrost electrostatic underlying glass. The material was dyed with malachite green with acid fuchsine and toluidine blue, Van Gieson, Groccot, were selected as the most suitable dyestuffs. The picture was processed with a microscope ZEISS Axiostar Plus connected with a camera OLYMPUS C5060 WZ and a multimedia PC. The software used was Quick Photo Camera 2.1, GIMP 2.2.

Cell deformation modelling

For estimation of the water potential we used the Höfler's diagram (Fig. 2). It is difficult to determine the exact volume of the cell, i.e. the ratio of its volume with one hundred percent content of water (later on as "healthy cell"). We estimated it through assuming that oxidative stress during a high insolation event results in water loss. The cell is distorted only in one dimension – the width (w) – whereas both length (l) and height (h) remain most unchanged. We could assume relative volume of the cell in simplified point of view, which is adequate to the width of both diseased and healthy cell ratios. This relation was named the cell deformation level (Fig. 3). The original width undistorted of cell (full turgor) is usually unknown. From the measurements carried out on undeformed mesophyll cell across the radial cut, we could conclude that their very variable width was roughly linear dependent on the cell's length. This fact was revealed by linear regression. Since we regard the cell length in the process of enhanced water loss in autonomous areas as a constant, we can use the above discussed linear function for estimation of the original width in deformed cells of particular length, and calculate the cell deformation level considered (in our simplified model) as identical with relative the volume of the cell (Salisbury and Roos, 1992).

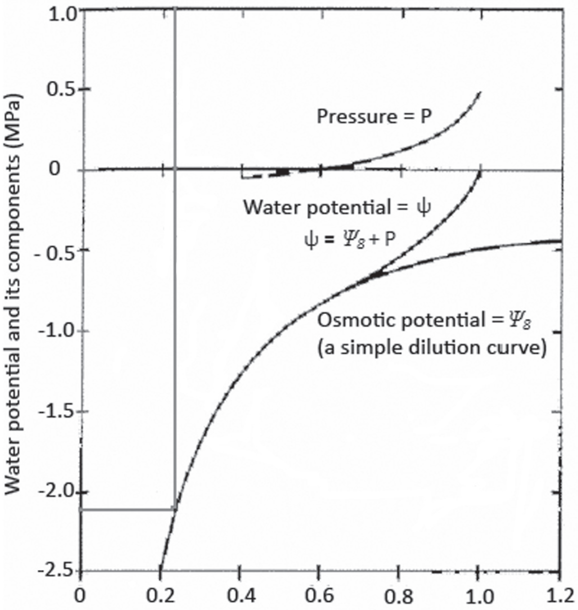


Fig. 2. Hőflers diagram (according to Salisbury and Ross, 1992). Graphic expression of relation between osmotic potential Ψs, pressure potential P and water potential Ψw

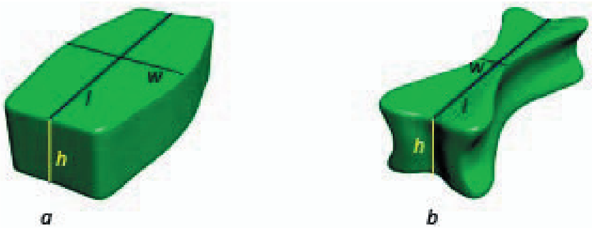


Fig. 3. Model of mesophyll cell deformation affected by reactive forms of oxygen (ozone) a – intact cell, b – deformed cell, l – length of cell, w – width of cell

Results and discussion

We observed significant cell deformations across radial cross-section of damaged needle segments. The cells were deformed by characteristic contraction accompanied with water potential drop. Deformed cells penetrate irregularly into the zone of cells which are still healthy. The intact cells are predominantly mitotic active, and their undisturbed protective mechanisms meet their function, and withstand the stress (Fig. 4). It was found that the average length of undeformed and deformed mesophyll cells was the sum. The deformation level of damaged cells was defined based on the ratio between widths of deformed and original cell of the same length. The median is of 0.289 (Fig. 5). Relative volume of damaged cells is proportional to the level of their deformation. Median of the water potential has the value of – 2.12 MPa, standard deviation is 1.12 MPa (Fig. 6). Cell width to height ratio is expressed through the cell shape index. Median of the shape index was established in monitored segments as follows: for healthy cells in the amount of 0.591, and for diseased ones 0.187. Standard deviation achieved 0.220 for intact cells, while 0.081 for damaged ones (Fig. 7). Dependence of the healthy cell width to its length is approximation linear (Fig. 8). Cell shape index indicates certain disease level showing at the final stage irreversible modification take place in mesophyll tissues. Its scope has adverse impact to the energy management and weakens metabolic functions of the cells. It was found that even single year needles often starts to form segregation layer in abscise zones and phelogen activity is increasing there, this results in premature aging, featured with subsequent defoliation of needles from the stem (Fig. 9). Scaling the leaf area down takes place for needles damaged by ozone (and by other reactive forms of oxygen), resulting also in vitality weakening of the whole tree. Premature elder needle shedding is a consequence of it. In the highest stations of middle-mountain the age of said needles reaches three, rarely even four years.

Conclusions

Structural analysis of the needles damaged by oxidative stress showed permanent changes in both covering and mesophyll tissues. Scope of damage achieved up to conductive tissues. Histological image showed qualitative deformations within locations of damaged cells. Frequent autonomous zones of atrophied cells featured with osmotic activity were observed within mesophyll. Local occurrence of the hypertrophy of fully turgescent cells has been found. Oxidative stress accelerates needle ageing as well as their premature fall.

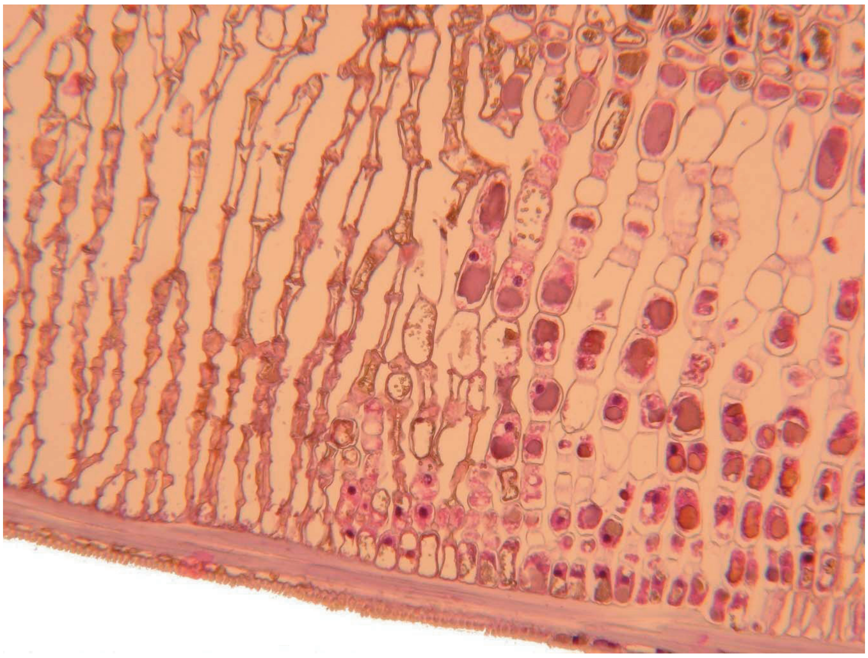


Fig. 4. Radial cross-section of damaged cells, zone of mitotic activity and healthy cells. Coloring: Hematoxylin-eosin

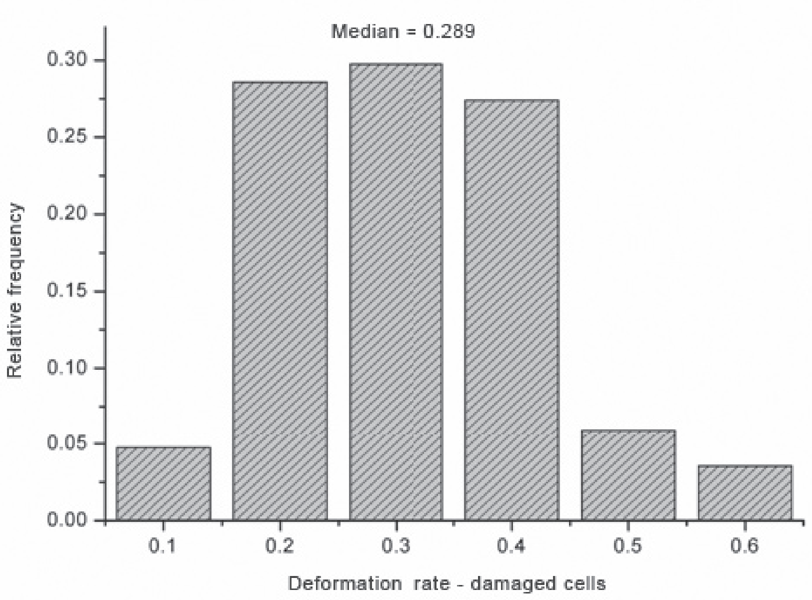


Fig. 5. Deformation level in damaged cells

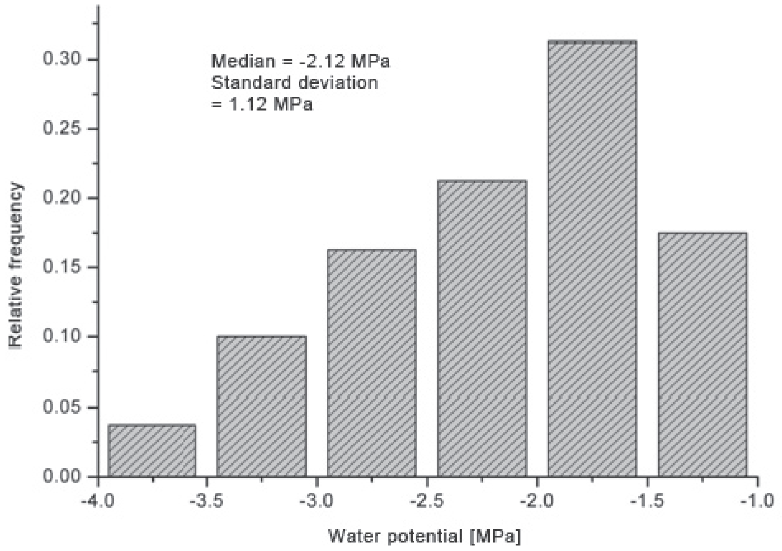


Fig. 6. Water potential of damaged cells

Acknowledgement

This study was supported from financial grant by the Department of Countryside protection of the Czech Ministry of Environment (project MŽP SP/1b7/189/07).

References

Bergendi, Ĺ. 1988. *Superoxid a iné bioreaktívne formy kyslíka* [Superoxide and other form of oxide]. Bratislava: Veda. 194 p.

Dotzler, M., Schutt, P. 1990. Long lasting effects of O_3 and SO_2 on the sensitivity to drought in two clones of Picea abies (L.) KARST. *Eur. J. Forest Path*., 20: 59–63.

Hippeli, S., Elstner, E.F. 1997. OH-radical-type reactive oxygen species: a short review on the mechanism of OH-radical and peroxinitrite toxicity. *Z. Naturforsch*., 52: 555–563.

Mangel, K., Ziegler, H. 1986. Einfluß von Ozon und saurem Nebel auf die Strukur der stomatären Wachspfropfen in den Nadeln von Picea abies (L.) KARST [Effects of ozone and acid mist on the epicuticular way in the stomatal antichamber of needles of P. abies (L.) Karst]. *Forstw. Cbl*., 105: 234–238.

Osswald, W.F., Elstner, E.F. 1986. Mechanismen der pathologischen Pigmentbleichung bei Pflanzen [Mechanism of pathological pigment bleaching in plants]. *Ber. Dtsch. bot. Ges*ell., 99: 341–365.

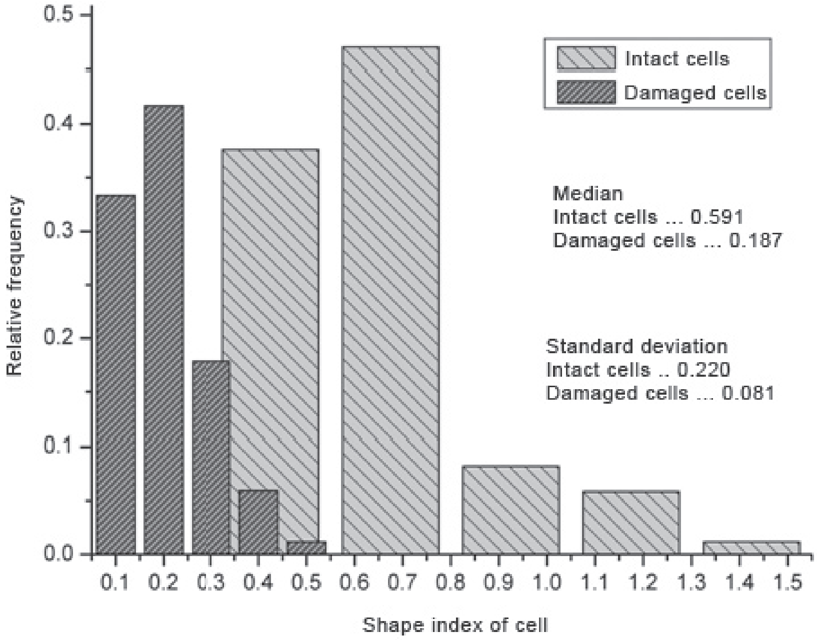


Fig. 7. Cell shape index – indicator of a damage rate

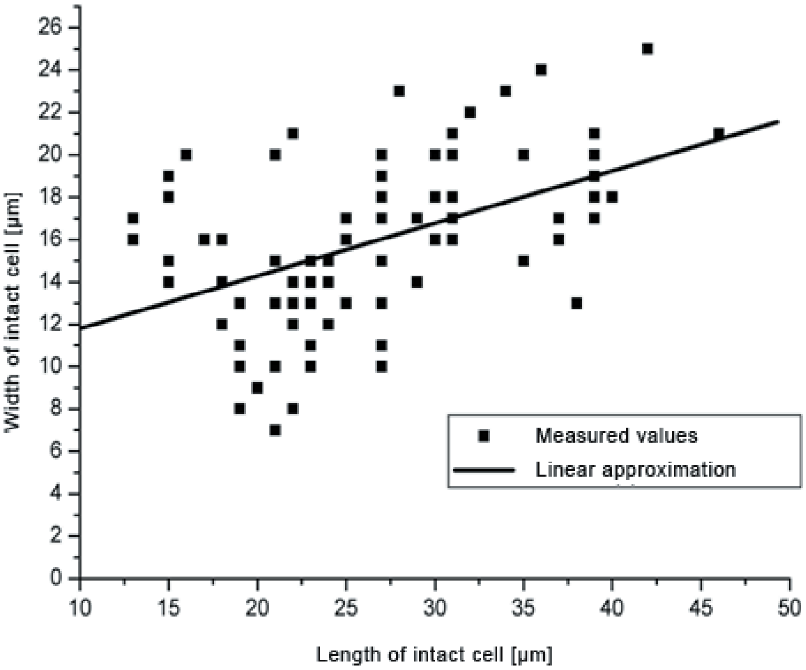


Fig. 8. Dependence of healthy cell width on its length

Fig. 9. Initiation of the defoliation with generating the segregation layer (A – one year old, B, C – two years old)

Piterková, J., Tománková, K., Luhová L., Petřivalský, M., Peč, P. 2005. Oxidativní stres: Lokalizace tvorby aktivních forem kyslíku a jejich degradace v rostlinném organismu [Oxidation stress. Locating the active oxygen evolution and its degradation in plant organism]. *Chem. Listy*, 99: 455–466.

Purvis, A.C., Shewefelt, R.L., Geogrenie, J.W. 1995. Superoxide production by mitochondria isolated from green bell pepper fruit. *Physiol. Plant*., 94: 743–749.

Salisbury, F.B., Roos, C.W. (eds). 1992. *Plant physiology*. Belmont, Calif.: Wadsworth Pub. Co. 682 p.

Symptomy oxidativního stresu v jehlicích smrku ztepilého (*Picea abies* L. Karst.)

Souhrn

Ve vyšších polohách středohoří bývají smrkové porosty poškozeny oxidativním stresem způsobeným především vysokými koncentracemi ozonu. Molekulární kyslík a jeho radikálové deriváty vyvolávají fotooxidaci fotosyntetických pigmentů, což vede k snížení výkonu fotosyntézy a inhibici růstu smrků.

Dochází k narušení redoxní rovnováhy buňky, a tím k oxidačnímu poškození buněčných komponent. Nastává snížení vodního potenciálu buňky až na hodnotu – 2.12 MPa a její deformace.

Práce sleduje, ve zkoumaném souboru poškozených buněk jehlic smrku ztepilého, stupeň deformace mezofylových buněk v autonomních oblastech pod diskolorovanou zónou epidermis a hypodermis, poměr četnosti výskytu nemocných buněk ke zdravým buňkám, stanoví stupeň deformace nemocných buněk a změny jejich vodního potenciálu.

Při oxidativním stresu během vysoké insolace dojde k ztrátám vody, buňka se zužuje pouze v jednom rozměru, šířce, přičemž délka a výška buňky zůstává prakticky stejná.

Received October 29, 2009
Accepted June 23, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Population and seasonal dynamics of Eriophyid mites in birch stands in the Krušné hory Mts (Czech Republic)

Emanuel Kula

Department of Forest Protection and Game Management, Mendel University, Zemědělská 3, 613 00 Brno, Czech Republic, E-mail: kula@mendelu.cz

Abstract

Kula, E. 2010. Population and seasonal dynamics of Eriophyid mites in birch stands in the Krušné hory Mts (Czech Republic). *Folia oecol.,* 37: 61–66.

Long term (1995–2007) and seasonal population dynamics of two gall mites *Acalitus rudis* (Canestrini) and *Eriophyes leionotus* (Nalepa) was examined in birch (*Betula pendula* Roth) stands in the Krušné hory Mts. *E. leionotus* showed a gradual continual increase probably affected by changes in air pollution load and food quality. *A. rudis* indicated a six-year cycle of population dynamics. Overwintering deutogynes of *A. rudis/E.leionotus* were activated from mid-April/late on April, when sum of effective temperatures reached a value of 50.8/60.5 °C, and birch buds began to burst. On the basis of seasonal dynamics, termination of the creation of erinea and galls, it is possible to qualify *A. rudis* and *E. leionotus* as monovoltine. Partial differences between the eriophyid mites in the spring induce creation of galls and their leaving in autumn are affected by the host and its response to site conditions.

Key words

Acalitus rudis, *Betula pendula,* bionomics, *Eriophyes leionotus*, Eriophyidae, Krušné hory Mts (Ore Mts), population ecology, seasonal dynamics

Introduction

Forest ecosystems in the Krušné hory Mts, are often heavy attacked by eriophyid mites. Knowledge on the bionomics and harmfulness of gall mites feeding on forest trees is quite insufficient (Jeppson et al., 1975). Gall-forming mites *Acalitus rudis* (Canestrini) and *Eriophyes leionotus* (Nalepa) (Vaněčková-Skuhravá, 1996a) belong to the crown fauna of birch *Betula pendula* Roth in the region of the Krušné hory Mts (Czech Republic). These species create specific galls on leaves of birch (Buhr, 1965; Schnaider, 1991) the quantity of which reflects the rate of the attack (Buchta et al., 2004). Over the broad spectrum of study sites, the most progressive attack to birch leaves by eriophyid mites was observed at 500–700 m a.s.l. in stands aged less than 40 years (Kula et al. 1999, 2000; Buchta and Kula, 2005). An increased feeding activity of eriophyid mites can negatively affect photosynthesis and induce physiological stress in the host plant. This fact has been reported also by Puchalska (2006) for *Oligonychus ununguis* Jacobi sucking on *Picea glauca* Conica, by Mobley and Martini (1990) for *Tetranychus urticae* (Koch) feeding on apple and pear leaves and by Andrews and La Pre (1979) for *Tetranychus pacificus* (Mc Gregor) on almond tree. The background of this fact is accumulation of phenolic substances in plant tissues (Puchalska, 2006; Kolodziej, 1976).

In spite of partial data of Keifer et al. (1982), the life cycle of the examined eriophyid mites feeding on birch has not been sufficiently known yet. Vaněčková-Skuhravá (1996b) described the bionomics of the univoltine mite *Eriophyes tiliae* ssp. *liosoma* sucking linden leaves in climatic conditions of Central Europe. The activity of overwintering deutogynes coincides with the budbreak in linden, because the sucking begins on unfolding leaves where galls have already been created at the beginning of May. The highest population density of *E. tiliae* was reached in mid-June when all developmental stages could be noted. In the first half of July, the frequency of mites on leaves decreased, and the occurrence of the new generation of deutogynes was evident.

The aim of this paper is to determine the population density of *A. rudis* and *E. leionotus* depending on changes in the basic climatic characteristics and to specify the phenology of occurrence and the seasonal dynamics of Eriophyidae colonizing birch stands in the Krušné hory Mts.

Material and methods

Population dynamics of eriophyid mites was examined on permanent sample trees in birch stands (aged 15–60 years) at four altitudinal transects from 500 to 1,000 m a.s.l. (100 m interval) situated in the area of the eastern Krušné hory Mts (Fig. 1). Branches were sampled from various parts of the tree profile at the end of June and August (1995–2007). Cohorts consisting of 70 leaves were taken from the individual branches with galls of eriophyid mites in a spring aspect. The total data at the level of transect and year were compared with precipitation totals and temperature means (meteorological stations CHMI Měděnec and Nová Ves v Horách).

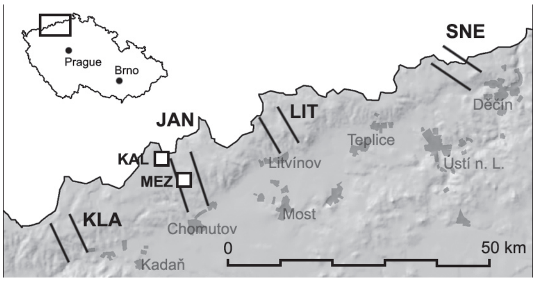


Fig. 1. Altitudinal transects and separate experimental birch stands in the Ore Mountains. Transects: KLA – Klášterec, JAN – Janov, LIT – Litvínov, SNE – Sněžník. Experimental plots: KAL – Kalek, MEZ – Mezihoří

The seasonal dynamics of eriophyid mites was studied at the Janov transect: Kalek locality (altitude 760 m, 50°34'23.712" N, 13°18'4.211" E) and Mezihoří locality (altitude 660 m, 50°32'3.446" N, 13°21'44.244" E) (Fig. 1). The temperature in the studied stands was measured continually, with using a digital thermometer. Phenology of birch leaves unfolding was evaluated in 20 trees over a one-week period during spring season in 2005. In the same year the occurrence of developmental stages of eriophyid mites was determined by washing leaves in 75% ethanol at 14-day intervals always in three sample trees in Kalek and two sample trees in Mezihoří. In the Mezihoří locality, *E. leionotus* was a dominant, while *A. rudis* occurred in the Kalek locality. The methodology of Zacharda et al. (1987) for washing mites with ethanol was adapted for sampling mites from birch. A sample – twig with 70 leaves – was put in a bottle (0.7 l) and shaken in about 100 ml 75% ethanol. After sedimentation the number of individuals in the sample was determined with a microscope.

In the selected group of 240 leaves (4 trees each 60 leaves) in each locality, the increase of gall density was assessed based on the percentage of the attacked area.

Thermometers with shaded sensors were placed in the lower crown parts (6 m above the ground) representing the tree part with the highest occurrence of eriophyid mites (Buchta et al., 2004). Temperature was measured at 1-hour intervals. The sum of effective temperatures (SET) was determined as the sum of positive mean temperature values >5 °C. Birch phenophases were evaluated according to the modified methodology of the phenological stations of the Czech Hydrometeorological Institute (Chmi, 1987; Kaňová and Kula, 2003). The extent of leaf unfolding and foliage was classified with degrees 10%, 50%, 75% and 100% across the whole vertical crown profile, separately for each sample tree.

Results

Population dynamics of eriophyid mites

In 1995–2007, the trend in the fluctuation in the attack intensity by eriophyid mites changed differently. In spite of significant differences in the occurrence of galls between particular transects, the trends of dynamic changes for the given mite species were congruent. In the studied area of the Krušné hory Mts, *A. rudis* was characterized by two significant culminations of the attack on leaf area (1999 and 2006), whereas the occurrence of *E. leionotus* increased continually (from 1995 to 2007).

Significant differences occurred in the attack intensity (in spite of similarity in the general trend) between particular transects. *A. rudis* showed changes in the attack dynamics in the Klášterec transect and partly in the Sněžník transect (heavy attack). In the Janov transect, the trend did not become significantly evident. In the Litvínov transect, low population density was not possible to evaluate (Fig. 2). *E. leionotus* attack was concentrated in the Klášterec transect (at the most in 2000, fluctuation and slight decrease in abundance) and Janov transect (at the most in 2007). In the Litvínov transect, the occurrence was noted as late as in 2005 showing a slight increase till 2007. *E. leionotus* has not been noted in the Sněžník transect (Fig. 3).

Population density of eriophyid mites having attacked birch did not correlate either with the course of annual precipitation totals or with the mean annual temperatures within the period under study (11 years). The occurrence of eriophyid mites did not depend on the fluctuation in climatic factors (correlation coefficient of 0.16 for temperatures and 0.03 for precipitation totals).

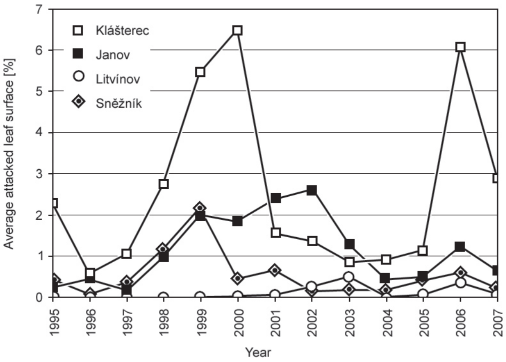


Fig 2. Average attack rates of *Acalitus rudis* in altitudinal transects in June 1995–2007

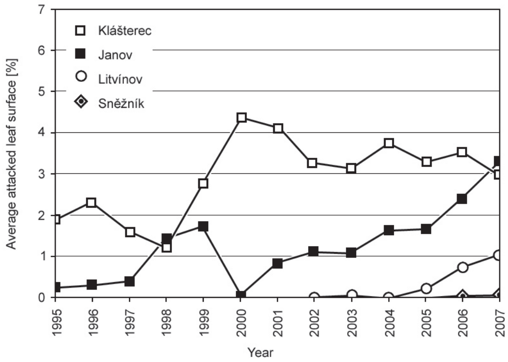


Fig. 3. Average attack rates of *Eriophyes leionotus* in altitudinal transects in 1995–2007

Seasonal dynamics and the life cycle of eriophyid mites

Overwintering deutogynes of *A. rudis* were activated from mid-April when SET reached a value of 50.8 °C, and birch buds began to burst. In the period mid-April to mid-May, spring activity on leaves culminated by creation of galls (erinea) the abundance of which was relatively low (17–40 individuals/70 leaves). In the period mid-May to mid-July, the free movement of the registered eriophyid mites on leaves was reduced because they lived under the protection of erinea. Individuals of a new generation left erinea from the end of July and their abundance culminated at the beginning of September. In connection with the change in food quality and approaching leaf fall deutogynes increase the intensity of leaving the erinea and search for places suitable for hibernation in buds and bark fissures (Fig. 4).

The first galls of *E. leionotus* were noted in mid-April on 13.3% checked leaves. The proportion of attacked leaves and the extent of erinea on the leaf area increased till the end of June when the proportion of attacked leaves amounted to 45.4%. The first erinea of *A. rudis* occurred on 39.5% leaves in the same period, and their increase stopped at the beginning of June when 60.8% attacked leaves were registered in a check sample (Fig. 5). The creation of galls was terminated in both mite species in May, and new galls and erinea occured only sporadically in June. Thus the abundance of galls was stabilized towards the end of the growing season. The distribution of leaves according to the attack degree was similar in both species. With increasing control area the number of attacked leaves decreased (Fig. 5).

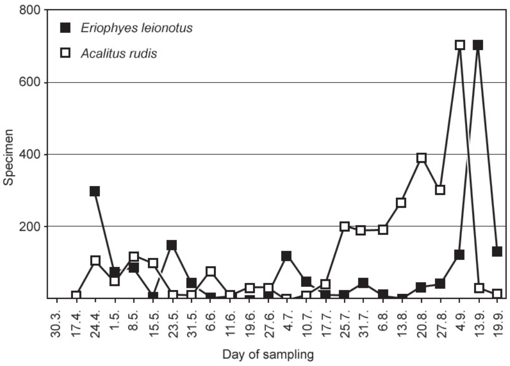


Fig. 4. Gall mites sampled from foliage on experimental plots in 2005 (average number per tree – 70 leaves)

Wintering deutogynes of *E. leionotus* were culminated late on April 24 when SET increased to 72 °C. The sporadic occurrence of galls on leaves was noted as early as April 17 (SET 60.5 °C, 95% trees budded). The development of leaves was advanced (70% trees with leaves long 1.5–3 cm, 30% trees fully budded). The spring abundance of activating deutogynes culminated in the 3rd ten-day period of April. Gradually with

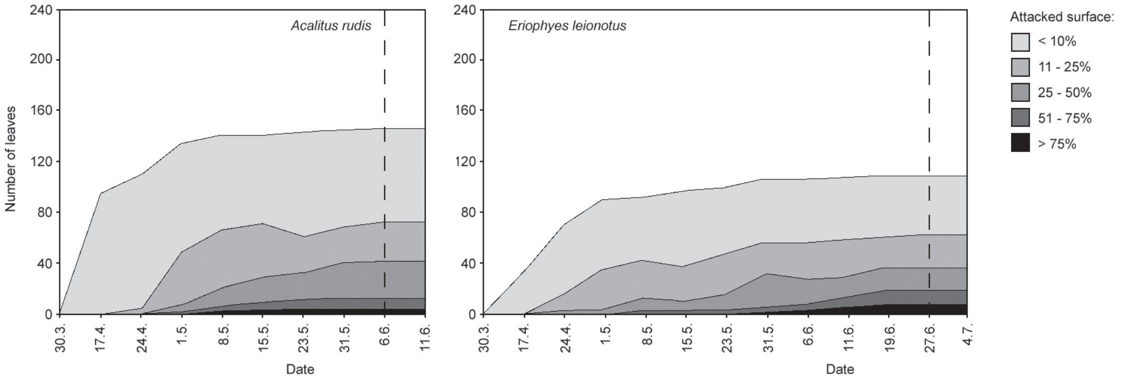


Fig 5. Growth of galls during vegetation season in 2005 (categorized by leaf surface damage)

the creation of galls, the number of individuals freely moving on birch leaves decreased. In June, the mite did not occur outside galls. Irregular but relatively numerous catching in July is interesting. The new generation left galls and searched for a place for wintering out of a leaf in the 3rd ten-day period of August, and culminated in mid-September. The drop in abundance in the 2nd ten-day period of September was related to the leaf fall (Fig. 4).

In both eriophyid mites, their seasonal dynamics is affected by birch budbreak. The mites differed in abundance in the spring season. The balanced spring proportion of *A. rudis* and the live fast decline in *E. leionotus* were probably related to the strategy of erinea and gall creation and the sampling of individuals of *A. rudis* was more effective with applying the method of washing. In both mites, the period of gall establishment can be specified by the beginning of budbreak termination ranging within 14 days. The occurrence of a new generation of *A. rudis* started before *E. leionotus*, the culmination points were shifted, and *E. leionotus* remained longer on leaves. Population density markedly increased in *A. rudis* (4 times) and *E. leionotus* (2 to 3 times).

Differences in temperature course between the localities affected budbreak and thus also the activity of wintering deunogynes. SET at the level of 50 °C is a limiting factor for both birch mites. The rate of gall creation and the development of a new generation can be partly differentiated in the course of temperatures. The Mezihoří locality is warmer than Kalek and the difference in SET exceeded 10 °C at the end of May (Fig. 6).

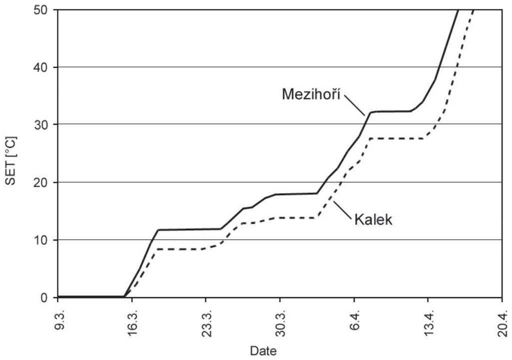


Fig. 6. Sum of effective temperatures over 5 °C recorded on experimental plots (2005)

Discussion

The population and seasonal dynamics of eriophyid mites is generally dependent on the course of weather in the period of termination of the dormancy of deutogynes, suitable food supply, intraspecific and interspecific competition, the occurrence of predators (Phytoseidae), pathogens or toxins (Lindquist et al., 1996). The area of the Krušné hory Mts is characterized by specific site conditions – due to high air pollution load from the 60s to 80s of the 20th century and its decline after 1995. The forests in the area responded by high proportion of birch in expense of the dying Norway spruce in the 80s of the 20th century (Kula, 2006), and by changed chemistry of the birch assimilatory organs *B. pendula* (Hrdlička and Kula, 2004) after 1995.

Nutrition quality requirements that birch gall mites put on their host plant are not known yet. On the basis of the observed trends in population dynamics, it is possible to express a hypothesis that *E. leionotus* responded to the drop air pollutant deposity and changes in the quality of assimilatory organs by a continual increase in abundance in the period 1995–2007. Since 2004, it has been spreading eastward to transects Litvínov and Sněžník. The mite also responded positively to liming of forest stands with dolomitic limestone (Kula, Matějková 2007, Kula 2009). In the studied period, it was not affected by occurrence of either extremely dry years (1997, 2001, 2006) or years above-normal in precipitation (1995, 2002). In *A. rudis* were noted cyclic changes in population dynamics – the maximum and minimum species abundance values alternated at intervals of six years. It follows that the ecological requirements of both eriophyid mites on birch are different. In *A. rudis*, climatic factors affecting the budbreak phase, the course of growing season and the food quality show stronger effects.

The activity of the two eriophyid mites on birch leaves was dependent on temperature. The SET values associated with the differences in the beginning of mite activity were affected by location. Particularly at higher locations there occurred shifts related to budbreak typical for Eriophyidae (Lindquist et al., 1996). Also Vaněčková-Skuhravá (1996b) mentions an association between the activity of various species of eriophyid mites and budbreak. Data of Lindquist et al. (1996) prove an increase in the abundance of deutogynes on leaves occurring in the spring aspect at the creation of galls, and before the end of the growing season when individuals of a new generation leave galls and leaves and look for a place for wintering at the base of buds or in bark fissures. The seasonal dynamics of the studied eriophyid mites displays the creation of erinea and galls proceeding up to the end of May; therefore it is possible to suggest that also *A. rudis* and *E. leionotus* create only one generation a year across the area of the Central Europe.

Conclusions

Eriophyid mites on birch (*B. pendula*) *A. rudis* and *E. leionotus* differ in population dynamics derived from the degree of attack to leaf area (1995–2007). *E. lionotus* shows a gradual continual increase probably affected by the change in air pollution load and food quality.

In *A. rudis*, a six-year cycle was indicated in population dynamics although no relationship was proved between the annual dynamics of the erinea occurrence and changes in temperature means and precipitation totals over the period 1996–2006. In year 2005 activation of wintering eriophyid mites (deutogynes) is related to budbreak and to the sum of effective temperatures, which reached (at the selected threshold of 5 °C) 50.8 °C in *A. rudis* and 60.5 °C in *E. leionotus*.

On the basis of the observed seasonal dynamics (the number of developmental stages on leaves in spring and autumn aspect, termination of the creation of erinea and galls in May) *A. rudis* and *E. leionotus* can be classified as monovoltine species. Certain differences between the eriophyid mites are in the spring start of the galls creation. They also differ in leaving the galls in autumn affected by the host tree and its response to the site conditions.

Acknowledgement

The project was financed from the funds of the Czech Science Foundation grant 526/05/0187 and Ministry of Education grant VZ MSM 6215648902. It was sponsored by the following companies and organizations: Netex Co. and Alusuisse Co. in Děčín, Municipal Office in Děčín, ČEZ Co. Prague, Cement Works Co. in Čížkovice, North-Bohemian Mines Co. in Chomutov and Dieter Bussmann Co. in Ústí nad Labem.

References

ANDREWS, K.L., LA PRE, L.F. 1979. Effects of pacific spider mites on physiological processes of almond foliage. *J. econ. Ent.*, 72: 651–654.

BUCHTA, I., KULA, E. 2005. Typologická charakteristika porostů břízy (*Betula* sp.) s výskytem hálkotvorných roztočů (Acari, Eriophyidae) [Typological characteristic of birch (Betula sp.) stands infested by gall mites (Acari, Eriophyidae)]. In KODRÍK, M., HLAVÁČ, P. (eds). *Uplatňovanie nových metód v ochrane lesa a ochrane krajiny. Zborník z medzinárodnej vedeckej konferencie, Zvolen, 8.–9. 9. 2005*. Zvolen: Technická univerzita vo Zvolene, p. 115–120.

BUCHTA, I., KULA, E., DRÁPELA, K. 2004. Ecological aspects of dispersion of gall mites in the vertical profile of the birch crown. *J. Forest Sci*., 50 (12): 566–572.

BUHR, H., 1965. *Bestimmungstabellen der Gallen (Zoo- und Phytocecidien) an Pflanzen Mittel- und Nordeuropas* [Comparative tables of galls (zoo- and phytocecidies) on plants of Central and Northern Europe]. 2 Vols. Jena: G. Fischer. 1572 p.

CHMI, 1987. *Návod pro činnost fenologických stanic – Lesní rostliny* [Guideline for phenological observation sites – Forest Plants]. Prague: Český hydrometeorologický ústav. 111 p.

HRDLIČKA, P., KULA, E. 2004. Changes in the chemical content of birch (Betula pendula Roth) leaves in air polluted Krušné hory Mountains. *Trees*, 18 (2): 237–244.

JEPPSON, L.R., KEIFER, H.H., BAKER, E. W., 1975. *Mites injurious to economic plants*. Berkeley: University of California Press. 614 p.

KAŇOVÁ, D., KULA, E. 2003. Dynamika růstu pupenů břízy Betula pendula Roth ve východním Krušnohoří [Dynamics of bud growth of birch Betula pendula Roth in eastern Ore Mountains]. In *Výsledky lesnického výzkumu v Krušných horách v roce 2002. Sborník z celostátní konference = Results of forestry research in the Ore Mts. in 2002. Proceedings from the national workshop, Teplice 27. 3. 2003*. Jíloviště Strnady: Výzkumný ústav lesního hospodařství a myslivosti, p. 132–144.

KEIFER, H.H., BAKER, E.W., KONO, T., DELFINADO, M., STYER, W.E. 1982. *An illustrated guide to plant Abnormalities caused by eriophyid mites in north America*. Agriculture Handbook, 573. Washington, D.C.: U.S.Government Printing Office. 178 p.

KOLODZIEJ, A. 1976. *Wymiana dwutlenku wegla i metabolizm wegla w fotosyntezie u zlocieni (Chrysanthemum morifolium L.) porażonych przez przedziorka chmielowca (Tetranychus urticae Koch)* [Carbon dioxide exchange and carbon metabolism in the photosynthesis of Chrysanthemum morifolium L. infested by Tetranychus urticae Koch]. PhD thesis. Warszawa: Warsaw Agricultural University. 93 p.

KULA, E. 2006. Činitelé ovlivňující stabilitu porostů břízy ve východním Krušnohoří [Factors affecting the stability of birch stands in the eastern Krušné hory Mts.]. In SLODIČÁK, M., NOVÁK, J. (eds). *Lesnický výzkum v Krušných horách. Recenzovaný sborník z celostátní vědecké konference, Teplice 20. 04. 2006*. VÚLHM VS Opočno, p. 111–144.

KULA, E., MATĚJKOVÁ, R. 2007. *Arachnoentomofauna stanovišť ovlivněných vápněním a hnojením a její dynamika* [Arachnoentomofauna of sites influenced by liming and fertilizing and its dynamics]. Research report. Brno: Mendel University of Agriculture and Forestry in Brno. 65 p.

KULA, E., RYBÁŘ, V., ZĄBECKA, J., 1999. Comments on the immediate health condition of birch stands in the air polluted region of the Ore Mts. *J. Forest Sci*., 45: 197–205.

KULA, E., RYBÁŘ, V., ZĄBECKA, J. 2000. Dynamic of health condition of birch stands in the eastern Ore Mts. In *Výsledky a postupy výzkumu v imisní oblasti SV Krušnohoří: Results and progress of the survey in the air-polluted area of the north-eastern Ore Mts. Sborník referátů z celostátního semináře konaného v rámci Phare-programu přeshraniční spolupráce CZ 9604.05.02.02.01.11.01, Teplice,* *4. 2. 2000*. Jíloviště-Strnady: Výzkumný ústav lesního hospodářství a myslivosti, Výzkumná stanice Opočno, p. 3–6.

Lindquist, E.E., Sabelis, M.W., Bruin, J. 1996. *Eriophyoid mites. Their biology, natural enemies and control*. Amsterdam, New York: Elsevier. 790 p.

Mobley, K.N., Marini, R.P. 1990. Gas exchange characteristic of apple and peach leaves infested by European red mite an twospotted spider mite. *J. Amer. Sco. Hort. Sci.,* 115: 757–761.

Puchalska, E. 2006. The influence of Oligonychus ununguis Jacobi (Acari: Tetranychidae) on photosynthetic activity and needle damage of Picea glauca “Conica“. *Biol. Lett*., 43: 353–360.

Schnaider, Z. 1991. *Atlas uszkodzenie drzew i krzewów powodowanych przez owady i roztocze* [Atlas of damage of trees and brushes caused by insects and mites]. Warszawa: PWN. 318 p.

Vaněčková-Skuhravá, I. 1996a. Eriophyid mites (Acari: Eriophyoidea) on trees and shrubs in the Czech Republic. *Acta Soc. zool. bohemoslov*., 60: 223–246.

Vaněčková-Skuhravá, I. 1996b. Life cycle of five eriophyid mites species (Eriophyoidea, Acari) developing on trees and shrubs. *J. Appl. Ent.,* 120: 513–517.

Zacharda, M., Pultar, O., Muška, J. 1987. Washing technique for monitoring mites in apple orchards. *Exp. appl. Acarol*., 5: 181–183.

Populační a sezónní dynamika vlnovníkovitých (Acari, Eriophyidae) v porostech břízy Krušných hor (Česká republika)

Souhrn

U vlnovníků *Acalitus rudis* (Canestrini) a *Eriophyes leionotus* (Nalepa) sající na listech břízy (*Betula pendula* Roth) byla sledována metodou jednotkových větví populační dynamika dle vytvořených hálek na listech (1995–2007) na trvalých vzorníkových stromech ve čtyřech transektech v Krušných horách. Sezónní aktivita obou vlnovníků byla zhodnocena na listech břízy (2005) metodou vymývání v etanolu.

E. lionotus vykázal pozvolný a kontinuální vzestup pravděpodobně ovlivněný změnou imisní zátěže a kvality potravy. U *A. rudis* byl naznačen šestiletý gradační cyklus přesto, že se nepotvrdila vazba meziroční dynamiky výskytu erineí se změnou teplotních průměrů a srážkových úhrnů v období 1996–2006.

Aktivace přezimujících vlnovníků (deutogynes) souvisí s rašením a sumou efektivních teplot, která při zvolené prahové hladině 5 °C dosáhla v roce 2005 u *A. rudis* 50,8 °C a u *E. leionotus* 60,5 °C.

Ze stanovené sezónní dynamiky (počty zachycených vývojových stádií na listech v jarním a podzimním aspektu, ukončení tvorby erineí a hálek v květnu) lze vlnovníky *A. rudis*, *E. leionotus* klasifikovat jako monovoltinní. Dílčí odchylka mezi vlnovníky v jarním nástupu k tvorbě hálek a jejich opouštění na podzim je ovlivněna živnou dřevinou (bříza) a její reakcí na stanovištní podmínky.

Received March 16, 2010
Accepted April 20, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Concentrations of inorganic nitrogen forms in the water in different biotopes in the Nature Reserve Alúvium Žitavy

Jaroslav Noskovič, Alexandra Palatická, Mária Babošová

Department of Environmental Sciences and Zoology, Faculty of Agrobiology and Food Resources,
Slovak University of Agriculture, Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic,
E- mail: jaroslav.noskovic@uniag.sk

Abstract

Noskovič, J., Palatická, A., Babošová, M. 2010. Concentrations of inorganic forms in the water in different biotopes in the Nature Reserve Alúvium Žitavy. *Folia oecol.*, 37: 67–74.

Over the years 2006–2008, the concentrations of N-NO_3^-, N-NH_4^+, N-NO_2^- were evaluated in dependence on sampling time and sampling site in the water of the Nature Reserve (NR) Alúvium (Aluvium) Žitavy, which is situated in the southwestern part of the Slovak Republic. On the basis of the results achieved, we can state that the mean concentration of nitrate nitrogen in the water of the Nature Reserve over the whole monitored period was 3.84 mg dm^{-3}. It represented 92.79% of inorganic nitrogen, the rest being represented by ammonium nitrogen and nitrite nitrogen. The highest mean concentration for the whole monitored period was found in March, and the lowest in June. In dependence on the sampling site, the highest mean N-NO_3 concentrations were found in the sampling sites. The sampling site No. 1 was situated on the inflow of the River Žitava into the Alluvium which proves that its important source is the river itself. The sampling site No. 4 was located in the narrowest part of Alluvium, where the river flows very quickly, oxygen is enriched, and therefore nitrification is more intensive. We found out statistically significant influence of the sampling year, month and site on the change in values of concentrations of this qualitative factor by analysis of variance. Ammonium nitrogen was quantitatively the second best represented by inorganic nitrogen. Of the total inorganic nitrogen it represented 5.53%. Its mean concentration over the whole monitored period represented 0.21 mg dm^{-3}. We recorded low concentrations of N-NH_4^+ over the whole monitored period in the winter months and the high ones in the months of July to September. In dependence on the sampling site we found out maximum mean N-NH_4^+ concentrations over the whole monitored period in the sampling sites with typical wetland ecosystems (sampling sites 2, 3, 5, 6). By analysis of variance for this indicator, it was found a statistically significant influence of the year, month and the sampling site on the change in its values. Nitrite nitrogen was the last represented from the monitored inorganic nitrogen forms. Of the inorganic nitrogen it represented 1.69%. Lower N-NO_2^- concentrations, compared to N-NO_3^- and N-NH_4^+, are probably related to its easy oxidation or reduction in waters. Minimum mean concentrations over the whole monitored period were in March, and April, and the maximum ones were in July. The sampling site had no statistical influence on the changes in N-NO_2^- concentrations.

Key words

ammonium nitrogen, Nature Reserve, nitrate nitrogen, nitrite nitrogen, wetland

Introduction

Nitrogen and phosphorus are primary nutrients limiting productivity in wetlands (Vitousek et Howarth, 1991). Their increased concentrations in surface water are unfavourable because of their participation in the eutrophication (Wittlingerová and Jonáš, 2004), and they are usually responsible for changes to ecosystem function and structure (Carpenter et al., 1998).

The nitrogen cycling process in wetlands involves both aerobic and anaerobic conditions. Nitrogen in the form of ammonium (NH_4) is released from decaying plants and animal matter under aerobic and anaerobic conditions in the process known as ammonification. The ammonium then moves to the aerobic layer where it is converted to nitrate (NO_3). Nitrate not taken up by plants or immobilized by adsorption onto soil particles can leach downward with percolating water to reach the groundwater supply or move with surface and subsurface flow. Nitrate can also move back to the anaerobic layer where it may be converted to nitrogen gas by denitrification, a bacterial process, and subsequently returned to the atmosphere (*Biogeochemical cycles*, 2001). Jansson et al. (1994; cit. Vaikasas et Rimkus, 2004) found out that nitrogen removal in wetlands mostly depends on the denitrification and sedimentation, and that water retention time is the most important factor for the removal of nitrogen.

Material and methods

Research area

The Nature Reserve (NR) Alúvium Žitavy is situated in the cadastral land of the town Hurbanovo and the village Martovce in the southwestern part of the Slovak Republic (*Krajinno-ekologický plán obce Martovce*, 2006). Its area is 32.53 hectares, and it was established as the Nature Reserve in 1993. The Alluvium lies in the interperineal area of the River Žitava, from its present estuary of the River Nitra to the village of Veľký Vék (assumed air line) (Szabóová, 1989). It is closely adjacent surrounding agrocenosis with remainders of meanders of the original water course of the rivers Nitra and Žitava. There is an open water line of the canal with dense bank vegetation in the central part of the Reserve. The northern part is enlarged and there is continuous vegetation of riparian forest. Wetland ecosystems are situated mainly in terrain depression at the edge of the alluvium of the River Žitava (Bridišová et al., 2006).

Its larger part is flooded along the year, but especially in spring. There are different biotopes, aquatic, wetland and riverine vegetation. Riverine forests, particularly willow stands, almost along Alluvium provide suitable ecological conditions for nesting and roosting of avifauna. There are more than 76 bird species occurring in this area (*Prírodná rezervácia Alúvium Žitavy*, 2006). Furthermore is very important for conservation of fauna and flora genetic resources (*Štátny zoznam osobitne chránených častí prírody a krajiny Slovenskej republiky*, 2007).

The NR Alúvium Žitavy is a part of the Protected Landscape Area Dunajské luhy (*Krajinno-ekologický plán obce Martovce*, 2006). The aim is to protect biotopes of European importance (riverine willow-poplar and alder wood forests) and the species of European importance (*Proterorhinus* sp., *Rhodeus amarus*, *Gobio albipinnatus*, *Bombina bombina*, *Lutra lutra*, *Citellus citellus*, species of national importance *Microtus oeconomus*) (Bridišová et al., 2006). Concurrently, NR Alúvium Žitavy is a part of the Special Protection Area SKSPA 005 Dolné Považie to which also belongs the proposed habitat of European importance 0159 Alúvium Žitavy (*Krajinno-ekologický plán obce Martovce*, 2006). The rare species of avifauna are for example *Ardea* sp., *Remiz* sp., *Botaurus* sp., *Circus* sp., *Anas* sp., *Acrocephalus* sp., *Charadrius* sp., *Locustella* sp., etc. In term of protected flora, there are *Leucojum aestivum* growing almost over the whole area of the NR and *Nuphar lutea* on water surface. *Ceratophyllum* sp., *Lemna minor* and *Lemna trisulca* form a typical green cover on the water surface. Along the interperineal area of the River Žitava, there is wetland vegetation from which communities of *Phragmites australis*, *Typha latifolia*, *Carex* sp. and *Scirpus* sp. are dominant (*Prírodná rezervácia Alúvium Žitavy*, 2006).

Sampling and processing of the material

Water sampling was carried out from the 6 sampling sites in the NR. The water samples were taken regularly during the years 2006–2008, on the 15th day of each month. The sampling sites were proposed to obtain the best possible data for the evaluation of changes in $N\text{-}NO_3^-$, $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ concentrations in water in dependence on the sampling time and site. We have established the following 6 sampling sites:

Sampling site No. 1 (47˚51'88" N, 18˚09'89" E, 121 m a.s.l.) – inflow of the River Žitava into the Alluvium. *Phragmites australis* and *Salix* sp. grow along the River Žitava. The average depth is 0.32 m.

Sampling site No. 2 (47˚51'92" N, 18˚09'25" E, 111 m a.s.l.) and **No. 3** (47˚51'83" N, 18˚09'25" E, 117 m a. s. l.) – these sampling sites are typical wetland ecosystems. There is a very dense vegetation of *Phragmites australis* and *Salix* sp. in this part of the NR. The water surface is covered by *Lemna minor*. Water in these sites flows very slowly, and the height of its level change is in dependence on weather during the year. The average depth is 0.30 m.

Sampling site No. 4 (47˚51'58" N, 18˚08'38" E, 129 m a.s.l.) – it is situated near a bridge on a road to the village of Martovce. It is also the narrowest part of Alluvium; where the water in the River Žitava flows most rapidly. There is a typical vegetation of *Phragmites australis*, *Salix* sp. and *Alnus* sp. on the banks of the River Žitava. The average depth is 0.40 m.

Sampling site No. 5 (47˚51'09" N, 18˚07'99" E, 116 m a.s.l.) and **No. 6** (47˚50'81" N, 18˚07'67" E, 121 m a.s.l.) – typical wetland ecosystems. Here, the River Žitava flows out of its watershed during rapid snow melting in spring and intensive precipitation events in summer. In comparison with the second and the third sampling site, the river floods the whole depression between the two slopes. In dry summer the water level decreases by about a few metres. This part of Alluvium is represented mainly by an open water area. *Typha latifolia*, *Phragmites australis*, *Alnus* sp. and *Salix* sp. grow along the river. The water surface in sampling site No. 6 is covered with *Lemna* sp. forming a typical green cover. Beyond this sampling site, the River Žitava flows into the River Nitra. The average depth in sampling site No. 5 is 0.26 m and 0.39 m in the sampling site No. 6.

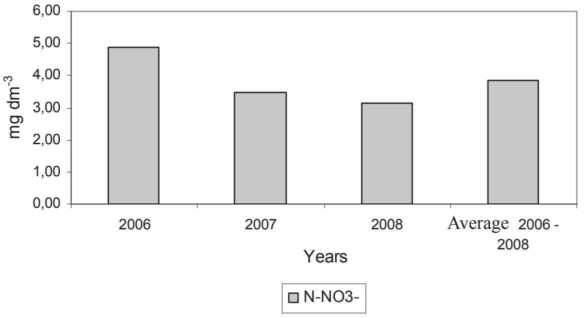


Fig. 1. Mean N-NO_3^- concentrations in years 2006–2008

The N-NO_3^- concentrations in the samples collected were determined spectrophotometrically, using a WTW nitrospectral in concentrated sulphur acid. The concentrations of N-NH_4^+ were determined spectrophotometrically, using indophenolic blue. The concentrations of N-NO_2^- were determined spectrophotometrically, using sulphanilic acid and 1-naphthylamine.

The results achieved were graphically processed in term of the sample time and the sampling site, and then processed statistically. All the statistical analyses were carried out using the statistic system Statgraphics Plus 5.0. The basic statistical characteristics of each data file were calculated for all monitored indicators (see Table 1). The statistical differences based on three qualitative factors (sampling year, sampling month, sampling site) were tested by analysis of variance. LSD test for testing statistical contrasts was used at significance level of 95% and 99%.

Results and discussion

From the obtained data it follows that N-NO_3^- represented 92.78% from the three monitored inorganic nitrogen forms. This result confirms that the nitrate nitrogen is the final nitrogen form in decomposition of organically fixed nitrogen, and that it is stable in aerobic conditions in water. The mean concentration over the whole monitored period was 3.84 mg dm^{-3} (see Fig. 1). The maximum mean concentration over the whole monitored period was obtained in March (9.22 mg dm^{-3}) and in this month in March 2006, the highest nitrate nitrogen concentration was measured (14.90 mg dm^{-3}). We suppose that the growth in N-NO_3^- concentration could be caused by increasing intensive nitrification of water of the NR and low N-NO_3^- uptake by autotrophic organisms. Nosković et al. (2007) examining water reservoirs Veľká Richňava, Malá Richňava and Veľká Vindšachta, also found out higher N-NO_3^- concentrations in spring season (spring circulation) than in summer (summer stagnation). Sebíň et al. (2007) found out maximum nitrate concentrations in surface water during snow melting in spring, minimum concentrations from June to August followed by a slight increase in autumn months. Rising nitrate concentrations during snow melting in spring and heavy autumn rains were also recorded by Růžičková et al. (2000) in lothic ecosystems situated in the catchments of the rivers Vydra and Křemelné (NP Šumava). The lowest N-NO_3^- concentration over the whole monitored period was recorded in July (1.36

Table 1. Basic statistical characteristics

Indicator	N-NO_3^-	N-NH_4^+	N-NO_2^-
Unit	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}
Count (n)	216.00	216.00	216.00
Average	3.84	0.21	0.06
Minimum	0.30	0.03	0.02
Maximum	16.10	0.76	0.40
Median	3.10	0.17	0.04
Mode	2.20	0.11	0.03
Variance	8.981	0.016	0.003
Standard deviation	2.997	0.127	0.057
Standard error	0.204	0.009	0.004
Range	15.80	0.73	0.38
Coefficient of variation (%)	78.041	60.403	95.154

mg dm^{-3}). In comparison with the increase in spring, the drop of N-NO$_3^-$ concentration was probably caused by inhibition of nitrification due to insufficient amount of oxygen dissolved. Sufficient content of dissolved oxygen as well as N-NO$_3^-$ consumption by primary producers in photosynthesis are important for nitrification process. Lellák and Kubíček (1991) state similar conclusions. Content of dissolved oxygen is reduced by microorganisms during organic matter decomposition, and it entail reduction of nitrification speed (*A wetlands monitoring program*, 2004). Kuníková et al. (2005) also found out a decrease of N-NO$_3^-$ concentration in summer in Anakonda wetland (an abandoned meander of the River Latorica). Mean N-NO$_3^-$ concentrations in dependence on a sampling time are illustrated in Fig. 2.

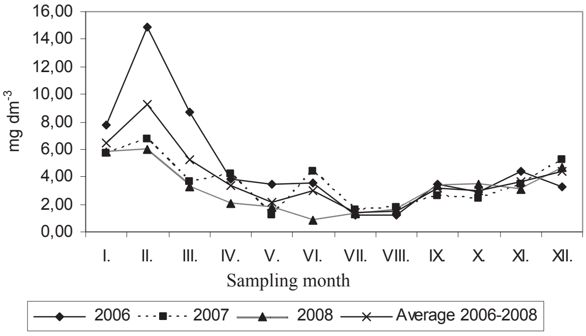


Fig. 2. Mean N-NO$_3^-$ concentrations depending on sampling time

In term of the sampling site (see Fig. 3), the highest mean N-NO$_3^-$ concentrations were in the sampling sites No. 1 (5.00 mg dm^{-3}) and No. 4 (4.66 mg dm^{-3}). We can suppose that the River Žitava is an important source of N-NO$_3^-$ because the sampling site No. 1 is situated on the inflow of the River Žitava into the Alluvium. High mean N-NO$_3^-$ concentrations in the sampling site No. 4 could be caused by favorable conditions for nitrification (sufficiency of dissolved oxygen as a result of water aeration because the river in this sampling site reaches maximum flow velocity). The lowest mean concentration was in the sampling site No. 6 (2.89 mg dm^{-3}). Low concentrations were recorded also in the sampling sites No. 2, 3 and 5 (wetland ecosystems). There is dense wetland vegetation on the banks and water surface is covered by common duckweed. Organic matter from dead vegetation cumulates in organic sustains in water. Content of dissolved oxygen in water decreases in consequence of oxidation of organic substances and results in nitrification inhibition. This is characteristic mainly for the summer season. In addition, it is known that phytoplankton intensively uptakes nitrate nitrogen from water.

All three qualitative factors (sampling year, month and site) were associated statistically with significant differences in amounts of N-NO$_3^-$. We found out a highly significant difference between the first and the second sample year (2006–2007) and another between the first and the third sample year (2006–2008). In dependence on the sampling site, highly significant difference was found between the sampling site No. 1 and No. 2, 3, 5 and 6, due to different biotopes in the individual sampling sites. Another high significant difference was between sampling sites No. 2 and 4, No. 4 and 6. We recorded negative correlation between nitrate nitrogen and ammonium nitrogen (r = –0.328) which is related to instability of ammonium nitrogen in oxidized conditions in water (N-NH$_4^+$ is easily biochemically oxidated to N-NO$_3^-$).

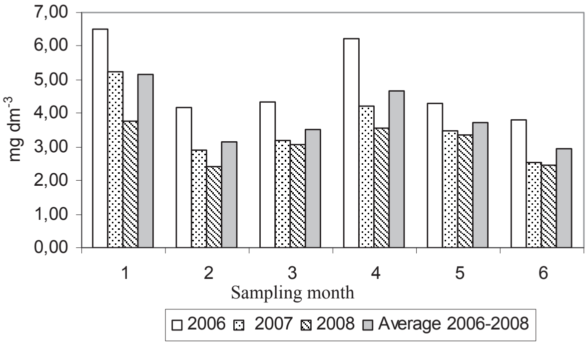


Fig. 3. Mean N-NO$_3^-$ concentrations depending on sampling site

Ammonium nitrogen represented 5.53% from the monitored inorganic nitrogen forms. Its mean concentration over the whole monitored period was 0.21 mg dm^{-3} (see Fig. 4). Mean concentrations of N-NH$_4^+$ in Anakonda wetland ranged from 0.155 to 0.575 mg dm^{-3} (Kuníková et al., 2005). From diagram showing mean N-NH$_4^+$ concentrations (see Fig. 5) it follows that low mean concentrations were in winter, minimum mean concentration of N-NH$_4^+$ was in February (0.12 mg dm^{-3}), and high concentrations in July and September (0.26 mg dm^{-3}). We suppose that the decrease in N-NH$_4^+$ concentration occurred in consequence of a low water temperature in the Nature Reserve in winter when organic nitrogen substances were not microbially decomposed. Subsequently, ammonia ions released. Ammonia ions originate during decomposition of organic maters containing nitrogen, and their occurrence is linked with lack of dissolved oxygen in water (Brveník, 2002). In waters with sufficient supply of dissolved oxygen, organic matter is oxidized by microorganisms to nitrate ions which are easily acceptable by plants (Klee, 1990; cit. Adam et al., 2001). Dependence between mean N-NH$_4^+$ values and mean dissolved oxygen values over the whole monitored period is showed in Fig. 6. From this figure it follows that N-NH$_4^+$ concentrations increased with decreasing dissolved oxygen content, mainly in the summer period when water in Alluvium had higher temperature and low content of dissolved oxygen. Negative correlation between N-NH$_4^+$ concentration and dissolved oxygen content in water (r = –0.47) was revealed by statistical evaluation.

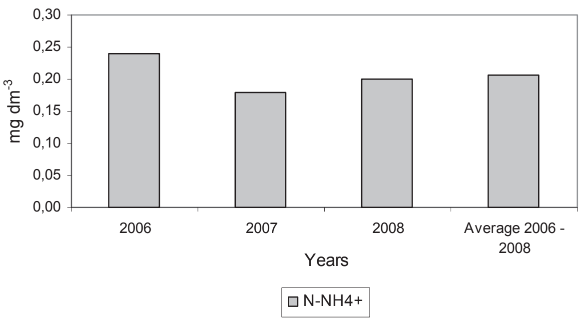


Fig. 4. Mean N-NH_4^+ concentrations in years 2006–2008

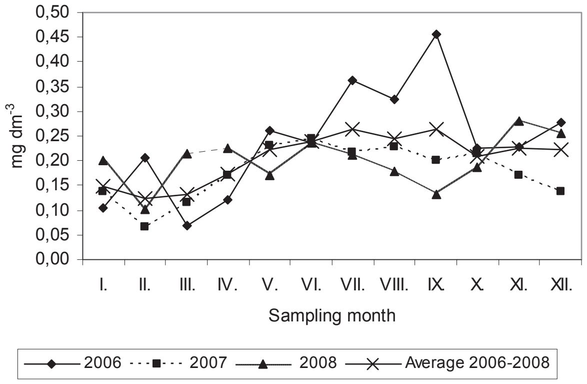


Fig. 5. Mean N-NH_4^+ concentrations depending on sampling time

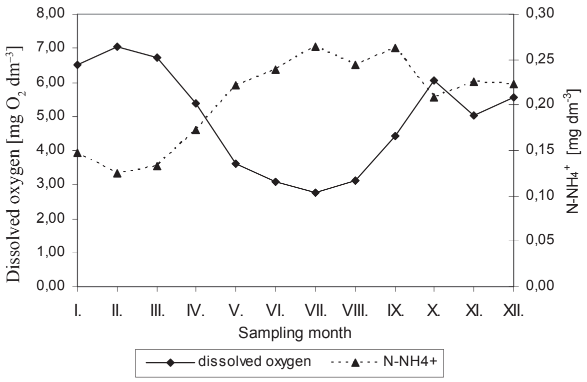


Fig. 6. N-NH_4^+ concentration and concentration of dissolved oxygen

N-NH_4^+ concentrations were gradually rising from March to the summer period. Their maximum was recorded in the already mentioned months of July and September. Kuníková et al. (2005) states that oxygen from nitrates is used during increased demands on oxygen. The increase in ammonium ions content in water can also be seen, as a result. Chalupová and Janský (2007) found out maximum concentrations of ammonium nitrogen in the summer period when N-NH_4^+ release was higher than its oxidation to nitrate nitrogen, as well as after vegetation season when the decomposition rate progressively increases. According to Patten (1990) ammonium nitrogen is the main inorganic nitrogenous compound in natural wetland ecosystems, and its values can reach 1–2 mg dm^{-3} in summer.

In dependence on the sampling site, we found out that maximum mean N-NH_4^+ concentrations over the whole monitored period in the sampling sites are typical wetland ecosystems (No. 2, 3, 5, 6) (see Fig. 7). We recorded the highest mean N-NH_4^+ concentrations in the sampling site No. 5 (0.33 mg dm^{-3}) and No. 6 (0.31 mg dm^{-3}) in 2006. Increased N-NH_4^+ concentrations in these sampling sites can be connected with over-reproduced phytoplankton forming algal bloom on water surface and consuming dissolved oxygen in water for own respiration. Huge amount of necrotized organic matter have accumulated at the bottom. With decomposition of organic matter, N-NH_4^+ was released, but it was not further oxidized, in consequence of low values of dissolved oxygen. The tendency in N-NH_4^+ concentrations was opposite to N-NO_3^- concentrations in the sampling sites. Beňačková and Noskovič (2004) also found out that the low content of dissolved oxygen caused the increase in N-NH_4^+ concentrations and decrease in N-NO_3^- concentrations.

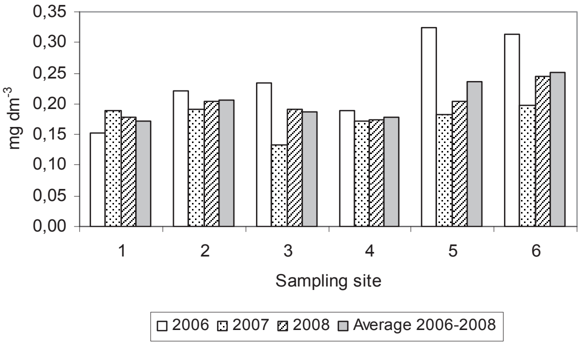


Fig. 7. Mean N-NH_4^+ concentrations in depending on sampling site

Similarly to N-NO_3^-, we found out that the sampling year, month and site statistically significantly influence values change of N-NH_4^+. In term of the sampling time, high significant difference was between the first and the second sampling year. In term of the sampling site, a high significant difference was between the sampling site No. 1, 4 and No. 6.

Nitrite nitrogen represented 1.69 % from the monitored inorganic nitrogen forms. Mean annual concentration of nitrite nitrogen over annual monitored years was gradually falling and its mean concentration over the whole monitored period represented 0.06 mg dm^{-3} (see Fig. 8). Compared with previous forms of inorganic nitrogen, low N-NO_2^- concentrations are related to be instable in waters, and they can be easily oxidized or reduced biochemically chemically (Pitter, 1990), nitrification is especially fast in presence of oxygen (Hudec, 1996). Mean N-NO_2^- concentrations in dependence on the sampling time are illustrated in Fig. 9. From this figure it follows that over the whole monitored period, the lowest mean N-NO_2^- concentration was in March and April (0.04 mg dm^{-3}) and the highest one in July

(0.10 mg dm^{-3}). We found out absolutely highest values of N-NO$_2^-$ from May to July 2006. Rapid increase in N-NO$_2^-$ concentrations in these months in 2006 can be explained by high water and air temperatures. KABELKOVÁ-JANČÁRKOVÁ (2002) states that in the summer, bacteria oxidizing nitrites grow less quickly than bacteria oxidizing ammonium. Nitrite production in biofilms is higher than its consumption. Therefore nitrites diffuse from biofilm into water when their concentration increases. According to BUDAY (2002), low concentrations of oxygen reduce the activity of nitrifying bacteria, whereby bacteria oxidizing nitrites react more sensitively than bacteria oxidizing ammonium.

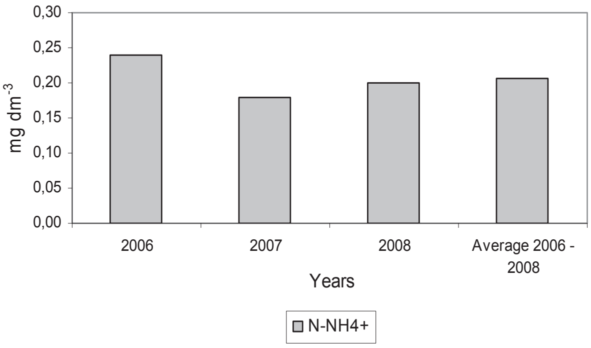


Fig. 8. Mean N-NO$_2^-$ concentrations in years 2006–2008

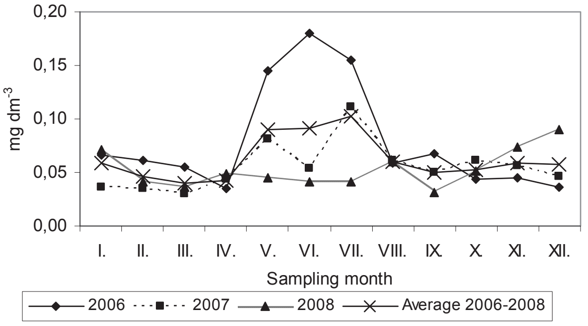


Fig. 9. Mean N-NO$_2^-$ concentrations depending on sampling time

Mean N-NO$_2^-$ concentrations in dependence on the sampling site are illustrated in Fig. 10. The highest mean concentrations in the individual sampling sites were measured in 2006 (0.06–0.09 mg dm^{-3}). Over the whole monitored period, the lowest mean concentration (0.06 mg dm^{-3}) was in all sampling sites, except for the sampling site No. 5 in which the highest mean concentration over the whole monitored period was found out (0.07 mg dm^{-3}).

Statistical evaluation revealed that N-NO$_2^-$ values were influenced significantly only by sampling year and month. Similarly to N-NO$_3^-$ and N-NH$_4^+$, statistically high significant differences were between 2006 and 2007 and between 2006 and 2008.

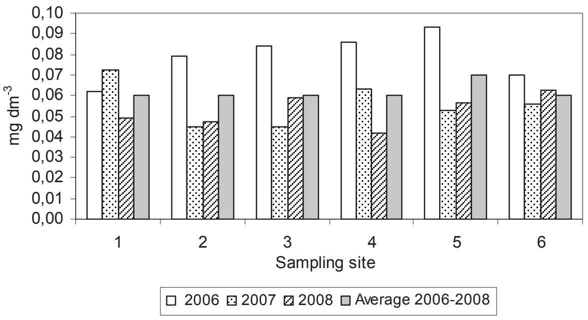


Fig. 10. Mean N-NO$_2^-$ concentrations depending on sampling site

Acknowledgement

This research was supported within the grant project VEGA 1/0275/08 “A Study of Abiotic and Biotic Parts of the Nature Reserve Alluvium Žitavy and Its Importance for the Biodiversity Conservation of Agricultural Landscape”.

References

ADAM, S., PAWERT, M., LEHMNANN, R., ROTH, B., MÜLLER, E., TRIEBSKORN, R. 2001. Physicochemical and morphological characterization of two small polluted streams in southwest Germany. *J. Aquat. Ecosystem Stress Recov.*, 8: 179–194.

A Wetlands Monitoring Programe. 2004. [cit. 2009-12-08]. <http://www.epa.gov/owow/wetlands/monitor>

BEŇAČKOVÁ, J., NOSKOVIČ, J. 2004. Evaluation of two inorganic forms of nitrogen in water of the Nature Reserve Žitavský luh. *Folia oecol.*, 31: 67–72.

Biogeochemical Cycles. 2001. [cit. 2009-11-26]. <http://www.na.fs.fed.us/spfo/pubs/n_resource/w.../wetlands7 biogeochemical%20cycles.ht>

BRIDIŠOVÁ, Z., BALÁŽ, I., AMBROS, M. 2006. Drobné cicavce prírodnej rezervácie Alúvium Žitavy [Small mammalians in the Nature Reserve Alluvium Žitavy]. *Chrán. Územia Slov.*, 69: 7–9.

BRVENÍK, B. 2002. Zhodnotenie kvality vody na prítokoch vodárenskej nádrže Málinec [Evaluation of water quality in inflows of the water reservoir Málinec]. *Vodohosp. Sprav.*, 9: 7–9.

BUDAY, J. 2002. *Intenzifikácia procesov odstraňovania dusíka z odpadových vôd – substrátová a produktová inhibícia nitrifikácie* [Intensification of processes of nitrogen removal from sewage waters – substrate and product inhibition of nitrification]. Bratislava: Výskumný ústav vodného hospodárstva. 92 p.

CARPENTER, S. R., CARACO, N.F., CORREL, D.L., HOWARTH, R.W., SHARPLEY, A.N., SMITH, V.H. 1998. Non-point-source pollution of surface waters with phosphorus and nitrogen. *Ecol. Appl.*, 8: 559–568.

Hudec, I. 1996. *Hydrobiológia* [Hydrobiology]. Bratislava: Príroda. 236 p.

Chalupová, D., Janský, B. 2007. Anthropogenic impact on selected oxbow lakes in the Elbe river floodplain. *J. Hydrol. Hydromech.*, 2: 86–97.

Kabelková-Jančárková, I. 2002. Dynamika nitrifikace v malém vodním toku [Dynamics of nitrification in a small water course]. *Vodohop. Sprav.*, 8: 221–224.

Krajinno-ekologický plán obce Martovce [Landscape-ecological plan of the nitttage Martovce]. 2006.

Kuníková, E., Tóthová, L., Hucko, P. 2005. Ekohydrologická štúdia ramien Latorice [Ecohydrological study of distributaries of the River Latorica]. *Vodohosp. Sprav.*, 9–10: 14–17.

Lellák, J., Kubíček, F. 1991. *Hydrobiologie* [Hydrobiology]. Praha: Univerzita Karlova. 257 p.

Noskovič, J., Jausch, M., Kočík, K., Beňačková, J. 2007. Hodnotenie koncentrácie anorganických foriem dusíka vo vodných nádržiach Veľká Richňava, Malá Richňava a Veľká Vindšachta [Evaluation of inorganic forms of nitrogen in the water reservoirs Veľká Richňava, Malá Richňava and Veľká Vindšachta]. *Acta Fac. ecol.*, 15: 21–27.

Pitter, P. 1990. *Hydrochemie* [Hydrochemistry]. Praha: SNTL. 568 p.

Prírodná rezervácia Alúvium Žitavy [The Nature Reserve Alluvium Žitavy] 2006. [cit. 2010-11-05]. <http://www.zitava.sk/zitava/zitava.php?page_id=turistika_prirodne_hodnoty_aluvium>

Růžičková, J., Hlásenský, I., Benešová, L., Piskáčková, L., Očásková, I. 2000. Chemismus vody v lotických ekosystémech povodí Vydry a Křemelné (NP Šumava) [Water chemism in lotic ecosystems in the catchment of the Vydra and Křemelné rivers (National Park Šumava)]. In *Limnologie na přelomu tisíciletí. Zborník príspevkov z konferencie. Časť Aplikovaná hydrobiologie, hydrobiochemie*, p. 323–329. [cit. 2009-12-08]. <http://www.sls.sav.sk/documents/Kouty-2000.pdf>

Sebíň, M., Pekárová, P., Miklánek, P. 2007. Evaluation and indirect estimation of nitrate losses from the agricultural microbasin Rybárik. *Biologia, Bratislava*, 5: 569–572.

Szabóová, A. 1989. *Príroda okresu Komárno* [Nature of the district Komárno]. Bratislava: Erpo. 216 p.

Štátny zoznam osobitne chránených častí prírody a krajiny Slovenskej republiky [National list of especialy protected parts of nature and landscape in the Slovak Republic]. 2007. [cit. 2009-10-25]. <http://uzemia.enviroportal.sk/main/detail/cislo/797>

Vaikasas, S., Rimkus, A. 2004. Modelling of nitrogen retention processes in the Nemunas Floodplain. *Trans. Lithuan. Univ. agric. Water Mgmt Inst. Lithuan. Univ. agric.*, 1 (4): 5–11.

Vitousek, P. M., Horwath, R. W. 1991. Nitrogen limitation on land and in the sea: how can it occur? *Biogeochem.* 13: 87–115.

Wittlingerová, Z., Jonáš, F. 2004. *Ochrana životního prostředí* [Protection of the environment]. Praha: Česká zemědělská univerzita. 131 p.

Koncentrácie anorganických foriem dusíka vo vode v rôznych biotopoch Prírodnej rezervácie Alúvium Žitavy

Súhrn

V priebehu rokov 2006 –2008 sa vo vode Prírodnej rezervácie Alúvium Žitavy, ktorá sa nachádza v juhozápadnej časti Slovenskej republiky, hodnotili koncentrácie $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$ v závislosti od času a miesta odberu. Na základe získaných výsledkov môžeme konštatovať, že priemerná koncentrácia dusičnanového dusíka vo vode PR za celé sledované obdobie bola 3,84 mg dm^{-3}. Z anorganického dusíka predstavoval až 92,79 %, zvyšok tvorili amónny a dusitanový dusík. Najvyššia priemerná koncentrácia za celé sledované obdobie bola zistená v mesiaci marec a najnižšia v mesiaci jún. V závislosti od odberového miesta boli najvyššie priemerné koncentrácie $N\text{-}NO_3^-$ v odberových miestach č. 1 a 4. Odberové miesto č. 1 sa nachádzalo na vtoku rieky Žitavy do alúvia, čo dokumentuje, že jeho významným zdrojom je samotná rieka. Odberové miesto č. 4 bolo lokalizované v najužšom mieste Alúvia, kde rieka prúdi najrýchlejšie, obohacuje sa o kyslík a preto nitrifikácia prebieha intenzívnejšie. Analýzou rozptylu sme zistili štatisticky významný vplyv všetkých troch kvalitatívnych faktorov (rok odberu, mesiac odberu, miesto odberu) na zmenu koncentrácií tejto formy dusíka. Kvantitatívne druhou najviac zastúpenou formou anorganického dusíka bol amónny dusík. Z anorganického dusíka predstavoval 5,53 %. Jeho priemerná koncentrácia za celé sledované obdobie bola 0,21 mg dm^{-3}. Nízke koncentrácie amónneho dusíka sa zaznamenali v zimných mesiacoch a vysoké v mesiacoch júl až september. V závislosti od odberového miesta najvyššie jeho

priemerné koncentrácie za celé sledované obdobie boli v odberových miestach mokraďového charakteru (odberové miesto č. 2, 3, 5, 6). Analýzou rozptylu pre tento ukazovateľ sme zistili štatisticky významný vplyv roka, mesiaca a miesta odberu na zmenu jeho hodnôt. Kvantitatívne najmenej zastúpenou anorganickou formou dusíka bol dusitanový dusík. Z anorganického dusíka reprezentoval 1,69 %. Jeho priemerná koncentrácia za celé sledované obdobie bola 0,06 mg dm^{-3}. Nižšie koncentrácie N-NO$_2^-$ v porovnaní s N-NO$_3^-$ a N-NH$_4^+$ súvisia pravdepodobne s jeho ľahkou oxidáciou resp. redukciou vo vodách. Za celé sledované obdobie boli najnižšie priemerné koncentrácie N-NO$_2^-$ v mesiacoch marec a apríl, najvyššia v mesiaci júl. Odberové miesta nemali štatistický vplyv na zmenu koncentrácií dusitanového dusíka.

Received December 15, 2010
Accepted February 24, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Spatial changes and succession of carabid communities (Coleoptera, Insecta) in seminatural wetland habitats of the Žitava river floodplain

Jana Porhajašová[1], Zbyšek Šustek[2], Jaroslav Noskovič[1], Jana Urminská[1], Peter Ondrišík[1]

[1]Department of Environmental Sciences and Zoology, Faculty of Agrobiology and Food Resources,
Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic,
E-mail: jana.porhajasova@uniag.sk
[2]Institute of Zoology, Slovak Academy of Science, Dúbravská cesta 9, 845 06 Bratislava, Slovak Republic,
E-mail zbysek.sustek@savba.sk

Abstract

Porhajašová, J., Šustek, Z., Noskovič, J., Urminská, J., Ondrišík, P. 2010. Spatial changes and succession of carabid communities (Coleoptera, Insecta) in seminatural wetland habitats of the Žitava river floodplain. *Folia oecol.*, 37: 75–85.

The carabid communities in the Žitava river floodplain were studied at four sites in the within-dike zone of the regulated river in 2006–2008. The communities were deteriorated to a considerable degree, characterized by a low number of species and individuals and by predominance of mesohydrophilous open landscape species over hydrophilous species. Occurrence of species was mostly very unstable, with a great between-year differences and no common trend. The representation of open landscape species was higher in the narrow stretch (ca. 150 m) of the within-dike zone than in the wider stretch (340–390 m). Their relative abundance was higher than that in other much narrower line or stripe formation of wooden vegetation in agrarian landscape. In spite of this, the Nature Reserve Alúvium Žitavy plays the role as a wetland biocentrum in the predominantly agrarian landscape.

Key words

Carabidae, Coleoptera, ecosystems, Nature Reserve

Introduction

The wetlands represent a significant regulator of hydrological regime of landscape and its macroclimate. They contribute to spatial and ecological diversity of landscape and provide habitats for many highly specialized species of plants and animals with an indispensable role in circulation of energy and matter in ecosystems. Wetlands belong to ecosystems with the highest species diversity and, simultaneously, to the most productive ecosystems of the moderate climatic zone. In cultural landscape they also increase its ecological stability and provide refuges to many rare species. The modern concepts of landscape protection and planning consider the wetlands as significant elements of the landscape stability skeleton (Naveh and Lieberman, 1983).

At the same time they were and still are subjected to enormous anthropogenic impacts or destructions since the early times of the human culture, especially because of development agriculture. In the recent two centuries, enlarging of settlements, regulation of rivers, navigation, energetic exploitation and spreading of invasive species considerably contribute to their degradation. From this reason they are represented in the landscapes by a wide scale of remnants, whose naturalness and evaluation of their ecosozological significance is an object of discussions (Mucha and Lisický, 2006). While botanists have developed clear concepts of classification of vegetation units of the wetlands (Zlatník, 1976; Michalko, 1986), in zoology many contradicting opinions exist on the matter. Even habitat preference of some species is interpreted completely inadequately in relationship to wetland ecosystems (c. f. Hůrka, 1996).

The floodplain of the Žitava river includes several isolated remnants of more or less preserved natural or rather seminatural wetland ecosystems (Palatická, 2009; Porhajašová et al., 2005). Unlike other rivers in Slovakia (e.g. Morava, Danube river), compact and extensive floodplain forests have not preserved here, the floodplain vegetation being mostly represented by narrow stripes of tree vegetation or by a mosaic of groups of trees, reed swamps or alluvial meadows along the river or around the adjacent water tables.

The Carabid assemblages in different floodplain ecosystems of the Podunajská nížina lowland were studied by Porhajašová et al. (2005) and Šustek (1984, 1994a, 1997), in South Moravia by Obrtel (1971, 1973) and Šustek (1972, 1994b) and in Austria by Zulka (1994). The Carabid fauna of the arable land surrounding the studied locality was recently studied in South Slovakia by Šustek (1994) and Porhajašová (2008a, 2008b).

The aims of this study are the following:
(1) to show the spatial and temporal dynamics of structural changes of carabid communities and, (2) their interaction with communities of other Arthropods, (3) to evaluate ecosozological status of the communities studied, (4) to show the role of the habitats studied as a refuges for the floodplain fauna (5) and to characterize the ecosozological significance of this nature reserve for carabids.

Material and methods

Study area and sampling sites

The Nature Reserve Alluvium of the Žitava river (32.53 ha) was designated in 1993, being provided with the 4th degree of protection (Palatická, 2009). It is situated in the southeastern Slovakia, in the Podunajská nížina lowland, between the town of Hurbanovo and Martovce village (Fig. 1). The surroundings lay in the oak vegetation tier (Raušer and Zlatník, 1966), but the major part of the surroundings is represented by arable land or settlements. The relief of the landscape shows that an extensive system of richly meandering branches of the Žitava and Nitra rivers existed here in the past. At present, the river is partly straightened and limited by protective dikes to a narrow zone with a richly diversified mosaic of aquatic habitats (mostly pleiso- or paleopotamal), reed and cattail swamps and remnants of floodplain forests (*Salici populeta, Populi alneta*) or new plantations.

The beetles and other Arthropods were pitfall-trapped in the years 2006–2008 at four sampling sites (Fig. 1):

A – 47°51'92" N, 18°09'25" E, altitude 117 m, width of the within-dike zone 390 m, a dense growth of *Carex* spp. and a sparse stand of *Salix* spp., coverage of trees layer 35%

B – 47°51'83" N, 18°09'25" E, altitude 116 m, width of the within-dike zone 360 m, a dense growth of *Carex* spp. and *Phragmites australis* a sparse stand of *Salix* spp., coverage of trees 30%, distance from the site A 334 m

C – 47°51'09" N, 18°07'99" E, altitude 116 m, width of the within-dike zone 140 m, a dense growth of *Carex* spp., majority of the site is formed by open water table, the whole site is often flooded, especially in spring and in rainy periods in summer, distance from the site B 2 100 m

D – 47°50'81" N, 18°07'67" E, altitude 121 m, width of the within-dike zone 150 m, a dense stand of *Carex*

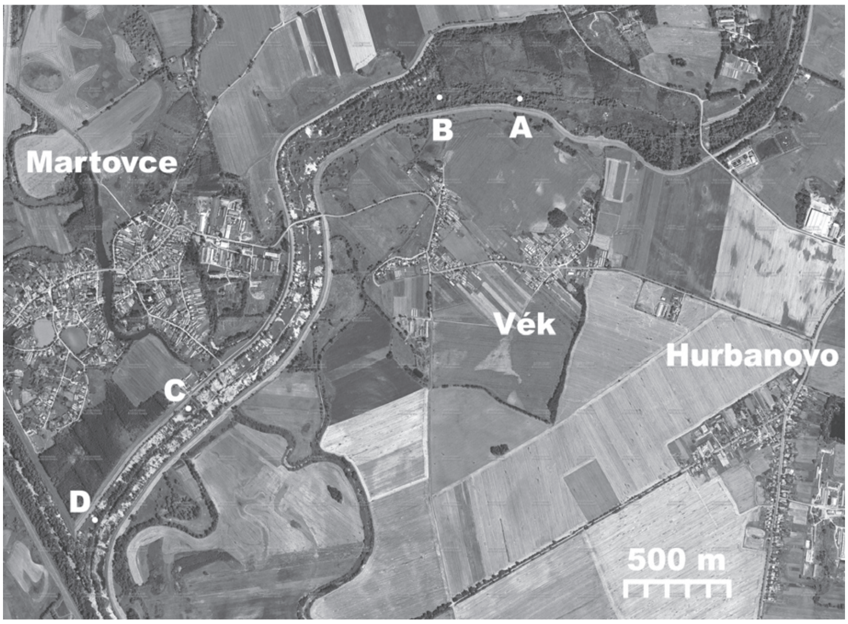


Fig. 1. Localization of four sampling sites in the Nature Reserve Alúvium Žitavy. The light patches in the left part of the alluvium correspond to open water table.

spp., on margins of permanent water tables *Typha latifolia* and *Phragmites australis* and a narrow, but continuous strip of alders and willows, coverage of trees 25%, distance from the site C 710 m.

Sampling Carabids and other Arthropods

One liter glass jars with 4% formalin and protected by a roof served as traps. In each site 1 trap was installed. Each year they were exposed from mid April to late October and emptied monthly.

Data analysis

The Carabids were identified to the species level, while other Arthropods to the level of orders or families. The nomenclature of Carabids was taken from Hůrka (1996). The data on their ecology were taken from Burmeister (1939), Knechtel and Panin (1944), Lindroth (1949) and Freude et al. (1976).The hierarchical classification of one-year samples was carried out by the unweighted average linkage method using the Whitaker's similarity index, the data being standardized by columns. The detrended correspondence analysis (DCA) and principal components analysis (PCA) were used for ordination of the data. The species diversity was expressed by the Shannon-Wienner's index (Poole, 1974). All these calculations were carried out in the program PAST and CAP. The direct ordination of the communities according to preference of species for vegetation cover and humidity was calculated according to Poole (1974). The sample scores were calculated as average of preference index of each species weighted by its abundance. Preference of Carabids for vegetation cover was expressed by a five degree semiquantitative scale (1 – open landscape species with discontinuous vegetation cover, 2 – open landscape species with continuous herbage vegetation species, 3 – eurytopic species, 4 – forests species, 5 – paludicolous species). The humidity preference was expressed by an eight degree semiquantitative scale (1 – extremely xerophilous, …, 4 – mesohydrophilous, …, 8 – polyhydrophilous) proposed tentatively by Šustek (2004).

Results

At all sampling sites we caught a total of 295 individuals and 33 species of Carabids (Table 1). At particular sites number of individuals and that of species fluctuated considerably in individual years, number of species from 2 to 13, number of individuals from 2 to 59. A constantly high number of individuals and species at one site during three years of investigation was recorded at the site C (37–59 individuals and 11–14 species), whereas at the site B their numbers were constantly very low (2–11 individuals and 2–5 species). Fluctuations in number of species and individuals at other sites did not show any coordination in time. At the site A their number dropped suddenly in 2007 and remained on that level in 2008, while at the site D it was continuously increasing from 2006 to 2008. All species (Table 1) are common or very common species in appropriate habitats in Slovakia. Only *Pterostichus cylindricus* (Herbst, 1784), *Diachromus germanus* (Linn., 1758) and *Drypta dentata* (Rossi, 1790) are more or less rare or local.

Representation of individual ecological groups of species in the entire material was very diversified (Figs 2 and 3). In spite of the alluvial character of the study area, the species of open landscape predominated (54.5%) followed by eurytopic species (12.1%), forest species (21.2%) and by paludicolous species (12.1%). Hence two thirds of species can be considered as xenocenous in the ecosystems studied. Similarly xerophilous or mesohydrophilous species represented even 48.5% of all species, while polyhydrophilous species expected to predominate represented only 30.3% of all species recorded.

Occurrence of individual species at particular sites and in particular years was very instable. Among the hydrophilous species, polyhydrophilous *Pterostichus anthacinus* (Illig., 1798) occurred abundantly and predominated (40.0%) only at the site C in 2008 and A in 2006 (10.7%). Hydrophilous *Carabus granulatus* (Linn., 1758) (48.2%) and moderately hydrophilous *Pterostichus melanarius* (Illig., 1758) (30.4%) dominated and simultaneously were also abundantly represented only in the site A in 2006 (Table 1). In 2007 and 2008, *Carabus granulatus* disappeared, being replaced by less hydrophilous *Carabus violaceus* (Linn., 1758) at all sites, especially in 2008. On the other hand, the typical open landscape species *Poecilus cupreus* (Linn., 1758) was abundantly represented and predominated (55.6%) only at the site C in 2007, but solely it occurred almost constantly in other years at the sites C and D. The strongly expansive open landscape species *Pseudoophonus rufipes* (De Geer, 1774) predominated (25.6%) only at site D in 2008, but similarly as *Poecilus cupreus* it occurred in small number of individuals in other years and sites (especially at site C and D). Other typical open landscape species, *Anchomenus dorsalis* (Pontopp., 1763), was more abundantly represented and predominated only in 2008 at the site C (24.4%) and to certain degree also at site D (10.3%).

Values of the Shannon-Wiener's index (Table 1) are very low (0.53–2.25) due a low number of species in most samples and due to a strong predominance of one species in some samples (e.g. *Pterostichus melanarius* at A6, *Poecilus cupreus* at C7, *Pterostichus antharicuns* at C8). Higher values of diversity indices were only in the samples C6 and D8 with more balanced representation of individual species. Equitability of most samples moved from 0.65 (C7) to 0.88 (C6 and D8). In the very poor samples (B6, B7 and D6) it was very high (0.90–1.00)

Table 1. Survey of Carabid species and number of individuals caught at four sites (A – D) in the Nature Reserve Alúvium Žitavy in years 2006–2008, their preference for humidity (H) and vegetation cover (V)

Species	H	V	Site and year											
			A			B			C			D		
			2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Acupalpus parvulus (Sturm, 1825)	4	1			8						1			
Agonum moestum (Duftschmidt,1812)	8	4	2					1			1			
Amara aenea (De Geer, 1774)	3	1					1		5			1		1
Anchomenus dorsalis (Pontopidan, 1783)	3	1									11			4
Anisodactylus binotatus (FabriciuS, 1787)	6	1	1											
Bembidion biguttatum (Fabricius,1779)	8	4								1				
Bembidion lampros (Herbst, 1784)	3	1							5		4		1	3
Brachinus crepitans (Linnaeus, 1758)	3	1							1	1				
Calathus fuscipes (Goeze, 1777)	4	1							9	1		3	1	
Calathus melanocephalus (Linnaeus, 1758)	3	1								1			1	4
Carabus granulatus (Linnaeus, 1758)	7	2	27											1
Carabus violaceus (Linnaeus,, 1758)	5	4		7	1			5				1		4
*Clivina fosso*r (Linnaeus, 1758)	6	4									3			
Diachromus germannus (Linnaeus, 1758)	7	1								6				
Drypta dentata (RossI, 1790)	8	5			1			2						
Dyschirius globosus (HerbsT, 1783)	8	5	1											
Harpalus latus (Panzer, 1797)	4	1							2					
Harpalus politus (Dejean, 1829)	4	1	1						5					
Harpalus tardus (Panzer, 1797)	2	1					1		1	1			1	1
Chlaenius nigricornis (Fabricius, 1787)	8	5	2							1	1			
Licinus depressus (Paykul, 1790)	2	1								5				
Ophonus azureus (Fabricius, 1799)	2	1							2					
Poecilus cupreus (Linnaeus, 1758)	4	1							1	33	1		1	1
Pseodoophonus rufipes (Panzer, 1797)	4	1	1				3		2	7	2		5	10
Pterostichus anthracinus (Illiger, 1798)	8	4	6		1			1	1		18			1
Pterostichus cylindricus (Herbst, 1784)	4	1					1							
Pterostichus melanarius (Illiger, 1798)	5	2	14									1	7	
Pterostichus niger (Schaller, 1783)	6	4		2				2		2	1			6
Pterostichus vernalis (Panzer, 1796)	8	5				1			1					
Pterostichus oblongopunctatus (Fabricius, 1787)	5	4					1							
Stomis pumicatus (Panzer, 1796)	8	2	1		2	1			1				2	2
Syntomus obscurogutatus (Duftschmidt, 1812)	5	2							1					
Trechus quadristriatus (Schrank, 1781)	4	1									2			1
Number of individuals			56	9	5	2	7	11	37	59	45	6	19	39
Number of species			10	2	4	2	5	5	14	11	11	4	8	13
Shannon-Wienner´ index			1.54	0.53	1.33	0.69	1.48	1.41	2.31	1.55	1.81	1.24	1.73	2.25
Equitability			0.67	0.76	0.96	1.00	0.92	0.88	0.88	0.65	0.75	0.90	0.83	0.88

Explanation of habitat preference scales (humidity scale: 2 – xerophilous, ..., 8 – polyhydrophilous; vegetation cover scale: 1 – open landscape species preferring discontinuous vegetation cover, 2 – open landscape species, 3 – eurytopic species, 4 – forests species, 5 – paludicolous species)

due to individual representation of a very limited number of species. Similar values of the Shannon-Wiener's index and equitability are typical for strongly deteriorated communities in urban parks (Šustek, 1984).

The great temporal instability of community structure is well visible even at the site C, which maintained a constantly high number of species and individuals (Table 1). Even the most abundant species *Amara aenea* (De Geer, 1774), *Anchomenus dorsalis, Diachromus germanus* occurred here only once over the study on period. There was a great difference between their maximum abundance in one year and occurrence in other year (*Calathus fuscipes* (Goeza, 1777), *Poecilus cupreus, Pterostichus anthracinus*).

The described instability of occurrence of species is reflected on patterns of clustering or position of

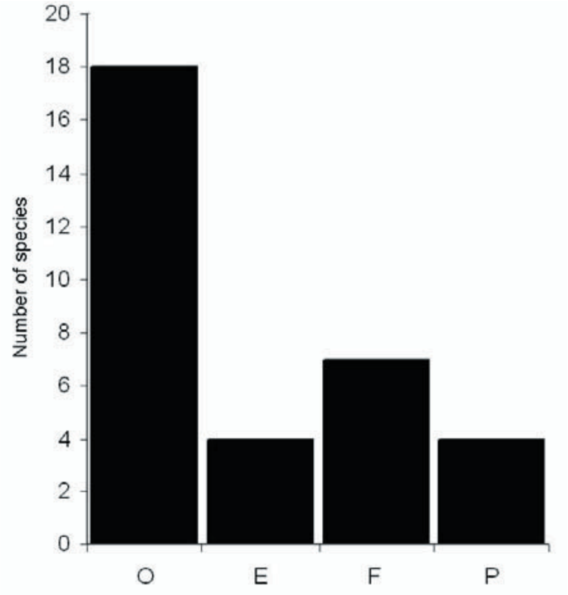


Fig. 2. Representation of species with different preference for vegetation cover in the whole material (O – open landscape species, E – eurytopic species, F – forest species, P – paludicolous species)

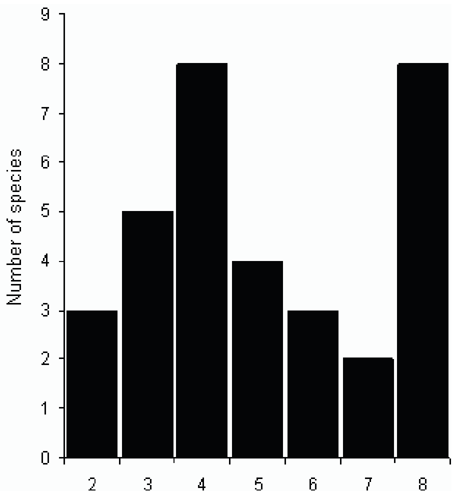


Fig. 3. Representation of species with different preference for humidity in the whole material (2 – moderately xerophilous species – 9 polyhydrophilous species)

samples in ordination spaces. In all cases an occasional coincidence of presence of a species considerably biases result of these analyses. According to Whitaker's index, the samples form the two distinct clusters at dissimilarity level 0.93. The first cluster includes predominantly the samples from the sites C and D and the samples from the site A from 2006 and B from 2007 (Fig. 4). This cluster reflects an increased relative abundance of the open landscapes species *Pseudoophonus rufipes* and *Poecilus cupreus*. The agglomeration of samples within this cluster, especially the separation of subcluster C6 and D6, is dependent on increased relative abundance of *Calathus fuscipes, Bembidion lampros* (Herbst, 1784) and *Amara aenea,* while the subcluster of the samples B7, D7 and D8 results from the absence of these species or their limited representation. The free attaching of the sample C7 and of the separate subcluster of samples A6 and C8 reflects increased relative abundance of the polyhydrophilous species *Pterostichus anthracinus*. The second cluster consists only of the samples from sites A and B with lower representation of open landscape species.

The samples and species in the biplot of the detrended correspondence analysis (Fig. 5) are arranged, in an continuous sequence, along the first axis according to decreasing humidity and along the second axis according increasing shadowing by wooden vegetation. The first axis explains 54.9% of variability of the species data, while the second axis 33.0%.

The PCA biplot (Fig. 6) separates four groups of samples. The sample from the site C from 2006,

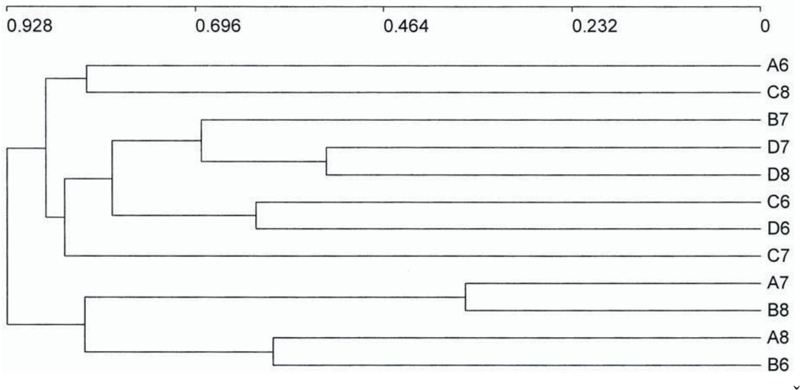


Fig. 4. Hierarchical classification of one-year samples from four sites in the Nature Reserve Alúvium Žitavy in 2006–2008 using Whitaker's index of similarity and data standardization by samples (A6, A7, …. D8 – samples from sites A–D from 2006–2008)

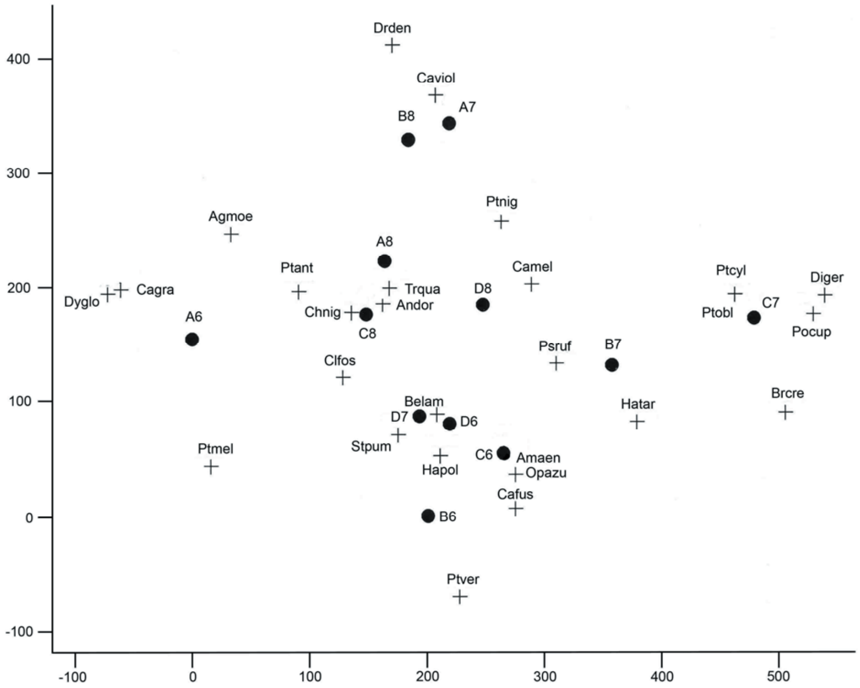


Fig. 5. Detrended correspondence analysis: biplot of the 12 one-year samples and 33 species from four sites in the Nature Reserve Alúvium Žitavy in 2006–2008 (abbreviations for samples and years as in Fig. 4, abbreviations of species consist of the first two letters of generic name and first three letters of specific name given in Table 1). The first axis represents humidity decreasing from left to right, while the second axis the shadowing decreasing from up to down.

characterized especially by a higher abundance of the open landscape species *Bembidion lampros, Harpalus politus* (Dejean, 1829) and *Calathus fuscipes,* takes an isolated position in the left lower part of the ordination space. The samples from the sites A from 2006 and C from 2008, characterized by co-occurrence of two hydrophilous species (*Carabus granulatus, Prerostichus anthracinus*) accompanied at the site A by further hydrophilous species, are situated in the right lower part of the ordination species. The sample from the site C from 2007 characterized by an abundant co-occurrence of *Poecilus cupreus* and *Pseudoophonus rufipes* takes an isolated position in the central upper part of the ordination diagram. In the central part of the diagram a close group of eight samples from the sites A, B and D is situated. Among them, samples from the site D are moderately shifted upwards. This group is characterized by less pronounced differences in quantitative representation of individual species and by a more balanced representation of principal ecological groups of species. Thus, the first axis represents the humidity gradient (increasing from left to right) and the second axis the gradient of vegetation cover preference (shadowing increasing from up to down). The PCA also illustrates the great instability of the community at the site C. The first axis explains 24.1% of variability, while the second axis 18.6%.

The direct ordination (Fig. 7) distinguishes the two groups of samples shown by correspondence analysis (Fig. 5) much clearer, being independent on incidental presence of a species, but integrating occurrence of species according to habitat preference. In the left lower part of the ordination diagram a closed group, including all samples from the sites D, two samples from the site C (2006 and 2007) and one from the site B (2007), may be noticed. This group is characterized by predominance of mesohydrophilous open landscape species. In the right upper part of the diagram a group of freely dispersed from the site A (all), B (2006 and 2008) and C (2008), which is shifted toward the precedent cluster. This group is characterized by a tendency to predominance of hydrophilous or even polyhydrophilous species demanding continuous shadowing by wooden vegetation. Relative position of individual samples shows a general trend to increased representation of more hydrophilous species in 2008 represented especially by *Pterostichus anthracinus* and *Drypta dentata*.

The detrended correspondence analysis (Fig. 6) and the direct ordination (Fig. 7) separate the samples from the narrower and wider part of the studied stretch of the floodplain (Fig. 1).

Among other Arthropod groups (Table 2), occurrence of Carabids showed an unclear positive correlation (r = 0.05–0.25) with *Diplopods*, *Isopods*, other *Coleoptera*, ants and mites (Fig. 8). In the case of *Diplopods*, *Isopods* and other *Coleoptera* this correlation reflects rather a reduced dependence between these groups and Carabids or a slightly similar habitat preference.

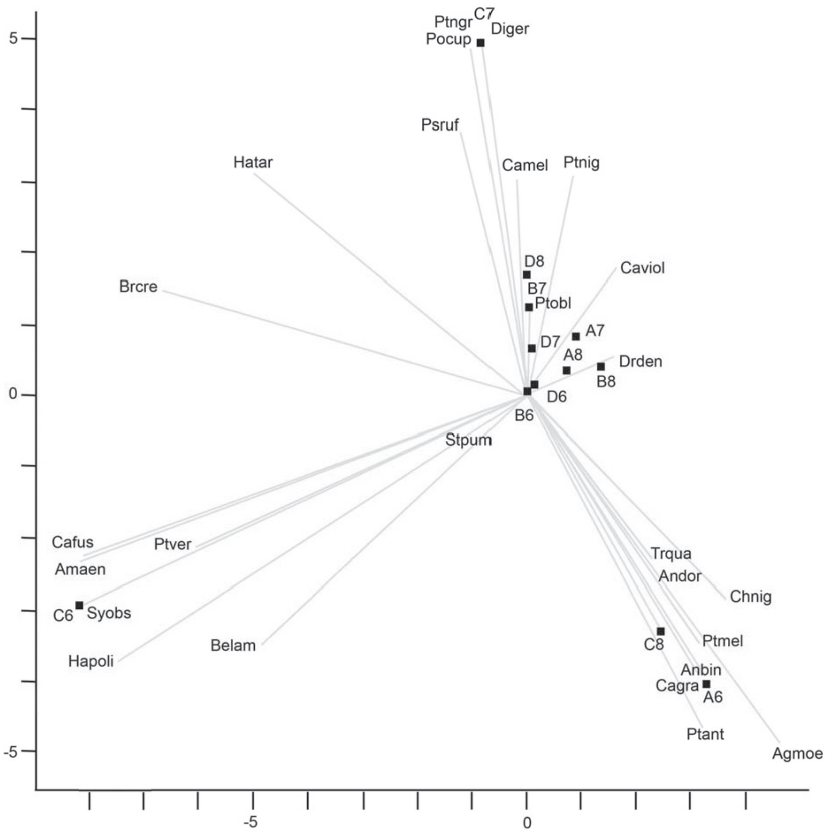


Fig. 6. PCA analysis of the 12 one-year samples and 33 species from four sites in the Nature Reserve Alúvium Žitavy in 2006–2008 (abbreviation of samples, years as in Fig. 4, abbreviations of species as in Fig. 5). The first axis represents humidity increasing from left to right, while the second axis the shadowing decreasing from up to down.

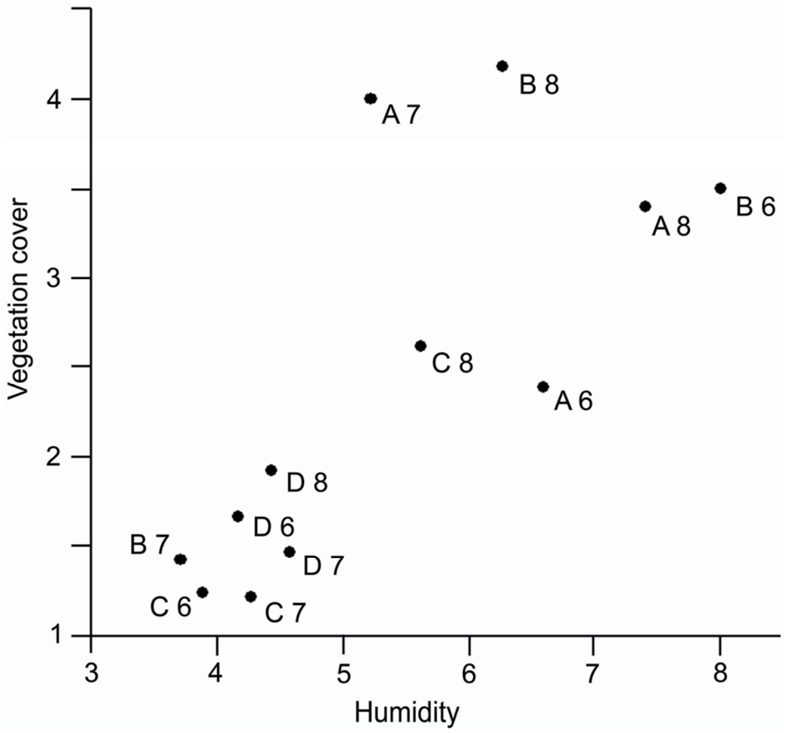


Fig. 7. Direct ordination of one-year samples at four sites in the Nature Reserve Alúvium Žitavy in 2006–2008. (Abscissa – vegetation cover preference: 1 open landscape species, 4 species demanding shadowing by wooden vegetation; ordinate – humidity preference: 3 mesohydrophilous species with reduced requirementsfor humidity, 8 – polyhydrophilos species, abbreviation for samples and years as in Fig. 4.)

A lower correlation between occurrence of Carabids and ants can express a trophic competition of both groups or even predation of Carabid larvae by ants. A stronger negative correlation (r = 0.37 and 0.41) exists between Carabids and spiders and harvestmen (*Opilionidea*), what might indicate a competition between Carabids and other two predatory groups taking a similar position in the trophical pyramid or even a predation of spider and harvestmen by some carabids. The negative correlation between the occurrence of carabids and collembolans might reflect predation of collembolans by carabids, but at any site the species of *Notiophilus*, the highly specialized collembolan-eaters, did not occurred. It is to be interpreted rather as consequence of different habitat preference.

Discussion

The carabid communities at all the study sites showed a very low cumulative abundance in comparison with the natural communities in natural floodplain forests (Obrtel, 1971; Šustek, 1972, 1994a, 1994b; Šustek, 2006; Zulka, 1994) or reed stands (Obrtel, 1973). A similarly low number of species, low cumulative abundance and unpredictable and clearly undetermined ecological structure of community was observed only in extremely deteriorated geobiocenoids of floodplain forests at margins of Bratislava (Šustek, 1984), in the Váh river floodplain (Šustek, 1997) or in remnants of floodplain forests (Dunajské kriviny) most affected by changes in hydrological regime in the area of the

Table 2. Abundance of arthopods at four sites (A–D) in the Nature Reserve Alúvium Žitavy 2006–2008 (6, 7 and 8)

Arthropod group	Site and years											
	A			B			C			D		
	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Diplopoda	47	19	38	0	3	22	0	0	20	1	7	35
Isopoda	181	35	65	23	109	200	12	12	20	5	25	107
Coleoptera	160	99	57	51	94	23	145	16	32	23	44	57
Opilionida	9	30	18	4	8	5	0	1	0	0	5	4
Carabidae	56	9	5	2	7	11	37	59	45	6	19	39
Formicoidea	72	54	60	34	70	37	210	15	119	136	42	68
Araneidea	88	124	79	91	180	133	103	36	54	30	81	78
Acarina	63	38	85	22	36	204	52	38	248	57	52	145
Collembola	242	162	628	276	266	198	137	30	526	216	71	133

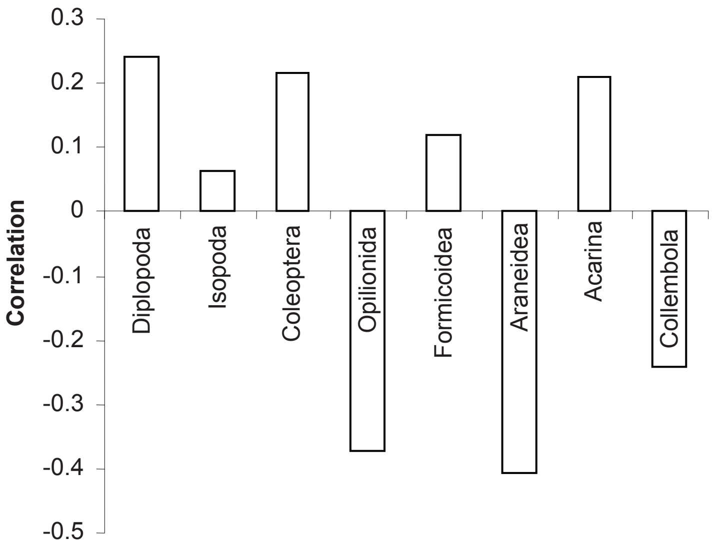


Fig. 8. Correlation coefficients of cumulative numbers of individuals of carabids and other predominant arthropod groups

Gabčíkovo hydraulic structures (Šustek, 2006). The low number of carabids is in an obvious discordance with high number of other arthropods (Table 2) and obviously results from the ecological state of the sites studied. It partly results from a longer overflooding of the studied sites.

Replacement of *Carabus granulatus* by *Carabus violaceus* and its subsequent gradation is one of two characteristic features of qualitative degradation of carabid communities in floodplain forests. It was observed in the Nature Reserve Apáli (about 6–7 km southwesterly from the Nature Reserve Alúvium Žitavy) and also in the Váh river floodplain area (Šustek, 1994a, 1997). Other similar manifestation is a striking gradation of *Carabus coriaceus* in floodplains forests of the Svratka river or the Čičovské mŕtve rameno Nature Reserve (Šustek, 1972, 1994a).

Penetration of open landscape species is obviously connected with the width of the within dike zone. The communities at sites A and B situated in the wide part of the zone (340–390 m) were obviously much less invaded by the xenocoenous species than the communities at sites C and D situated in the narrow part of the zone (140–150 m). However, the larger width of the within dike zone in the sites A and B was not able to compensate other unfavorable factors (probably disintegration of the tree layer and possibly also isolation of the locality), as can be shown by structure of carabid communities in various line formations of wooden vegetation in agrarian landscape, like hedges or windbreaks, where forest species can predominate, of course under favorable conditions, even in 20 m wide stretches (Šustek, 1992, 1994c). Isolation of the locality could influence composition of the carabid communities only in the case of stenotopic species of mesohydrophilous forests (normal and xerophilous hydrical series (Raušer and Zlatník, 1966) that are unable to fly. On the contrary, most species of floodplain forests (group of geobiocoens Salici Alneta) are able to fly and rapidly colonize even considerably isolated wetland localities (Šustek, 1994d).

The instability of representation even of open landscape species, as manifested especially at the site C (Table 1, Fig. 6) shows that the area studied is newly colonized each year from other immigration sources, in dependence of the actual crops in surrounding arable land and in other part of vegetation season. It is manifested, first of all, by mutual relation of *Poecilus cupreus* as a spring breeder and *Pseudoophonus rufipes* as and autumn breeder and seasonal changes of representation of these species in cultures of different crops (Cardamo and Spence, 1994; Porhajašová et al., 2008a). A similar pulse-like colonization by *P. cupreus* was also observed in the carabid communities in High Tatra damaged by wind disaster in November 2004 and additionally affected by fire (Šustek, 2009).

Conclusions

Comparison of the 12 one-year samples from the 4 sites in the Nature Reserve Alúvium Žitavy shows that the Reserve serves, to certain degree, as a refuge for a considerable number of hydrophilous carabid species in the purely agrarian landscape. However, their assemblages are instable over time and suffer from a strong species turnover from year to year. Structure of the carabid assemblages corresponds to the assemblages in the most deteriorated remnants of floodplain forests along the Váh river or in the most affected part of the Danube inland delta in the area of the Gabčíkovo hydraulic structures. From this point of Reserve view, the Reserve has a much greater significance for other plant and animal groups than for the carabids.

The carabid fauna from the surrounding fields or villages obviously interferes with the fauna in the reserve. This influence is particularly evident in the narrow part (140–150 m) of the floodplain (sites C and D), while in the wider part (340–490 m) of the alluvium this interference is limited. This part had a more natural structure of the assemblages over the whole investigation study period in spite of the fact that it was drier than the narrow part, where many standing water bodies could supply favorable conditions for the hydrophilous riverbank species.

Acknowledgement

The study was financially supported by the grant projects VEGA 1/0275/08, VEGA 1/0457/08, VEGA 1/0551/08 and VEGA 9/7079/07.

References

Burmeister, F. 1939. *Biologie, Ökologie und Verbreitung der europäischen Käfer. I. Band* [Biology, ecology and distribution of European beetles. Vol. 1]. Krefeld: Hans Goecke Verlag. 307 p.

Cardamo, H.A., Spence, J.R. 1994. Crop type effects on the activity and distribution of ground beetles (Coleoptera, Carabidae). *Envir. Ent.,* 23: 123–140.

Freude, H., Harde, K.W., Lohse, G. A. 1976. *Die Käfer Mitteleuropas. Band 2* [Beetles of Central Europe. Vol. 2]. Krefeld: Goecke & Evers Verlag,

Hůrka, K. 1996. *Carabidae of the Czech and Slovak Republics*. Zlín: Kabourek. 565 p.

Knechtel, W.K., Panin, S.A. 1944. *Oekologisch-zoogeographisches Studium an Coleopteren des Rumänischen Faunengebietes* [Ecological and zoographical study of Coleoptera in Romanian zoographical areas]. Études et recherches, Académie Roumaine, 25. Bucureşti. 199 p.

LINDROTH, C. H. 1949. *Die Fennoskandischen Carabidae 3. Allgemeiner Teil* [Ground beetles (Carabidae) of Fennoscandia 3. General analysis]. Göteborgs kungl. vetenskaps- och vitterhefts-samhälles handlingar. Ser. B4. Göteborg: Wettergren & Kerbers Förlag. 911 p.

MICHALKO, J. 1986. *Geobotanická mapa ČSSR, Slovenská socialistická republika* [Geobotanical map of the CSSR, the Slovak Socialistic Republic]. Bratislava: Veda, 165 p.

MUCHA, I., LISICKÝ, M.J. (eds) 2006. *Slovak-Hungarian Environmental Monitoring of the Danube. Results of the Environmental Monitoring based on the "Agreement between the Government of the Slovak Republic and the Government of the Republic of Hungary concerning certain technical measures and discharges in the Danube and Mosoni branch of the Danube 1995-2005. Slovak section. Danube Monitoring Scientific Conference 25–26 May, 2006, Mosonmagyaróvár, Hungary*. Bratislava: Podzemná voda. 286 p.

NAVEH, Z., LIEBERMAN, A.S. 1983. *Landscape ecology: Theory and Application*. New York: Springer Verlag. 356 p.

OBRTEL, R. 1971. *Soil surface Coleoptera in a lowland forest*. Acta sci. natur. Acad. Sci. bohemoslov. Brno, V. Praha: Academia. 46 p.

OBRTEL, R. 1973. *Soil surface Coleoptera in a reed swamp*. Acta sci. natur. Acad. Sci. bohemoslov. Brno, VI. Praha: Academia. 36 p.

PALATICKÁ, A. 2009. *Monitorovanie a hodnotenie kvality vody v Prírodnej rezervácii Alúvium Žitavy* [Monitoring and assessment of the water quality in the Nature Reserve Alúvium Žitavy]. PhD thesis. Nitra: Slovak University of Agriculture in Nitra. 245 p.

POOLE, R.W. 1974. *An introduction to quantitative ecology*. New York: McGraw Hill. 532 p.

PORHAJAŠOVÁ, J., PETŘVALSKÝ, V., URMINSKÁ, J. 2005. Monitorovanie výskytu epigeických skupín s dôrazom na čeľaď Carabidae (Coleoptera) v prírodnej rezervácii Žitavský luh [Monitoring of occurrence of epigaeic animal groups with accent of the family Carabidae (Coleoptera)]. *Acta fytotechn. zootechn*., 8: 57–61.

PORHAJAŠOVÁ, J., PETŘVALSKÝ, V., MACÁK, M., URMINSKÁ, J., ONDRIŠÍK, P. 2008a. Zastúpenie druhov čeľade Carabidae (Coleoptera) v závislosti od vstupov organickej hmoty do pôdy [Distribution of species of the family Carabid in dependence on input of organic material into soil]. *J. Cent. Eur. Agric*., 9: 557–565.

PORHAJAŠOVÁ, J., PETŘVALSKÝ, V., ŠUSTEK, Z., ONDRIŠÍK, P., URMINSKÁ, J. 2008b. Long-termed changes in ground beetle (Coleoptera: Carabidae) assemblages in a field treated by organic fertilizers. *Biologia, Bratislava*, 63: 1184–1195.

RAUŠER, J., ZLATNÍK, A. 1966. Biogeografie I [Biogeography I]. In *Atlas Československé socialistické republiky*. Praha: ČSAV, Ústřední správa geodézie a kartografie, mp. 21.

ŠUSTEK, Z. 1972. Carabidae a Staphylinidae jako složka přírodních geobiocenóz [Carabidae and Staphylinidae as a component of natural geobiocoenoses]. In *Sborník samostatných prací Biologické soutěže studentů škol II. cyklu*. Praha: Ústřední dům pionýrů a mládeže J. Fučíka, p. 1–57.

ŠUSTEK, Z. 1984. *Bioindikačné vlastnosti bystruškovitých a drobčíkovitých (Coleoptera, Carabidae et Staphylinidae) stredoeurópskeho veľkomesta* [Bioindicative properties of carabids and staphylinids (Coleoptera, Carabidae et Staphylinidae) of Central European cities]. PhD thesis. Bratislava: Institute of Experimental Biology and Ecology, Slovak Academy of Sciences. 364 p.

ŠUSTEK, Z. 1992. Windbreaks and line communities as migrations corridors for Carabids (Col. Carabidae) in the agricultural landscape of South Moravia. *Ekológia* (*ČSFR*), 11: 259–271.

ŠUSTEK, Z. 1994. Impact of pollution by nickel leaching rest on Carabidae, Silphidae and Staphylinidae in the surroundings of the nickel smelting plant at Sereď. *Biologia, Bratislava*, 49: 709–721.

ŠUSTEK, Z. 1994a. Classification of the carabid assemblages in the floodplain forests in Moravia and Slovakia. In DESENDER, K., DUFRÉNE, M., LOREAU, M., LUFF, M.L. MAELFAIT, J.P. (eds). *Carabid beetles: Ecology and evolution*. Dordrecht, Boston, London: Kluwer Academic Publishers, p. 371–376.

ŠUSTEK, Z., 1994b. Impact of water management on a Carabid community (Insecta, Coleoptera) in a Central European floodplain forest. *Quad. Staz. Ecol. Civ. Mus. St. Nat. Ferrara*, 6: 293–313.

ŠUSTEK, Z., 1994c. Windbreaks as migration corridors for carabids in an agricultural landscape. In DESENDER, K., DUFRÉNE, M., LOREAU, M., LUFF, M. L. MAELFAIT, J.-P. (eds). *Carabid beetles: Ecology and evolution*. Dordrecht, Boston, London: Kluwer Academic Publishers, p. 377–382.

ŠUSTEK, Z. 1994d. Bystruškovité CHKO Slovenský kras [Carabidae of the Protected Landscape Area Slovenský kras]. In ROZLOŽNÍK M., KARASOVÁ, E. (eds). *Chránená krajinná oblasť – biosférická rezervácia Slovenský kras*. Martin: Vydavateľstvo Osveta, p. 163–166.

ŠUSTEK, Z. 1997. Bystruškovité a drobčíkovité (Coleoptera, Carabidae et Staphylinidae) v lesných a brehových biotopoch v záujmovom území dolného toku Váhu [Carabidae and Staphylinidae of forests and riverbank habitats in the interest area of the Váh river downstream]. In KOŠEL, V. (ed.). *Environmentálna štúdia vodného diela Sereď – Hlohovec*. Final report. Bratislava: Pedohyg, p. 67–84.

Šustek, Z. 2004. Characteristics of humidity requirements and relation to vegetation cover of selected Central-European Carabids. In Polehla, P. (ed.). *Hodnocení stavu a vývoje lesních geobiocenóz.* Geobiocenologické spisy, 9. Brno: Mendelova zemědělská a lesnická univerzita, p. 210–214.

Šustek, Z. 2006. Carabid and Staphylinid communities as indicators of changes in floodplain forests in the area affected by the Gabčíkovo project. In Mucha, I., Lisický, M. J. (eds). *Slovak-Hungarian Environmental Monitorng of the Danube. Results of the Environmental Monitoring based on the "Agreement between the Government of the Slovak Republic and the Government of the Republic of Hungary concerning certain technical measures and discharges in the Danube and Mosoni branch of the Danube 1995–2005. Slovak section. Danube Monitoring Scientific conference 25–26 May, 2006, Mosonmagyaróvár, Hungary*. Bratislava: Podzemná voda, p. 175–181.

Šustek, Z. 2009. Veterná katastrofa vo Vysokých Tatrách a jej dopad na spoločenstvá bystruškovitých (Col. Carabidae) – výsledky z rokov 2007 a 2008 [The wind calamity in the High Tatras Mts and its impacts on Col. Carabidae – results from years 2007 and 2008]. In Fleischer, P., Matejka, F. (eds). *Windfall Research in the TANAP, 2008. Proceedings of the 3rd Workshop, Congress Center ACADEMIA, Stará Lesná, November 20–21, 2008*. Bratislava: Geophysical Institute of the Slovak Academy of Sciences, Research Station of the TANAP, State Forest of TANAP. 1 electronic optical disc (CD-ROM), p. 220–226.

Zlatník, A. 1976. Přehled skupin typů geobiocénů původně lesních a křovinných v ČSSR [Survey of groups of types of geobioceons primarily forest and shrubby in the C.S.S.R.]. *Zpr. Geogr. Úst. ČSAV v Brně*, 13 (3–4): 55–64.

Zulka, H. P. 1994. Natürliche Hochwasserdynamik als Voraussetzung für das Vorkommen seltener Laufkäferarten (Coleoptera, Carabidae). *Wiss. Mitt. Niederösterr. Landesmus.,* 8: 203–215.

Priestorové zmeny a sukcesia spoločenstiev bystruškovitých (Coleoptera, Carabidae) v poloprirodzených mokradných biotopoch v nive rieky Žitavy

Súhrn

Spoločenstvá bystruškovitých študované v rokoch 2006–2008 na štyroch lokalitách v Prírodnej rezervácii Alúvium Žitavy vykazovali vysoký stupeň narušenia a nestability. Indikoval ho nízky počet druhov a jedincov a prevaha mesohydrofilných druhov otvorenej krajiny nad hydrofilnými druhmi charakteristickými pre mokrade. Spoločenstvá vykazovali veľké medziročné rozdiely v druhovom zložení, bez zrejmého spoločného trendu. Výskyt druhov otvorenej krajiny bol vyšší v úzkom úseku (150 m) alúvia ako v širokom úseku (340–390 m), avšak aj tu bol ich výskyt vyšší ako v líniových formáciách drevinnej vegetácie širokých 10–20 m. Napriek tomu táto prírodná rezervácia plní úlohu biocentra pre mokradné druhy bystruškovitých v intenzívne využívanej poľnohospodárskej krajine.

Received December 15, 2009
Accepted March 9, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Dynamics of inorganic forms of nitrogen in soil of the Nature Reserve Alúvium Žitavy

Monika Sovišová[1], Peter Ondrišík[2]

Department of Environmental Sciences and Zoology, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic,
[1]E-mail: monika.sovisova@gmail.com, [2]peter.ondrisik@uniag.sk

Abstract

Sovišová, M., Ondrišík, P. 2010. Dynamics of inorganic forms of nitrogen in soil of the Nature Reserve Alúvium Žitavy. *Folia oecol.*, 37: 86–94.

There was studied dynamics of inorganic soil nitrogen in the Alluvium Žitavy Nature Reserve in the years 2008 and 2009. We observed variability in the individual inorganic nitrogen forms in soil samples differing in the sampling depth, soil moisture content, sampling site and date of the sampling. After comparing the contents of N_{in} over the research period, we found that higher values were in the first year (2008). Ammonium nitrogen values ranged from 3.80–16.87 mg kg^{-1} and its average over the research period was 7.24 mg kg^{-1}. The contents of this N form in 2008 were higher than in 2009. Nitrate nitrogen displayed the opposite trend. The values of nitrate nitrogen were within 0.44 to 9.28 mg kg^{-1} with an average of 2.03 mg kg^{-1}. The contents of this N form were higher in 2009. The content of ammonium nitrogen was found affected significantly by the year and date of sampling. The content of nitrate nitrogen was highly significantly influenced by the soil depth, year and sampling site. The coefficients of variation were high, consequently, there have not been identified correlations between the soil moisture content and amounts of the studied forms of inorganic nitrogen. The low values of nitrate nitrogen do not indicate a risk of pollution either of the groundwater or surface water.

Key words
ammonium nitrogen, nitrate nitrogen, soil, wetland

Introduction

Nitrogen is essential for growth and reproduction of all life forms, and except for legume crops and virgin soils with relatively high soil organic matter, soil N must usually be supplemented to sustain food, feed, and fiber production (Dinnes et al., 2002).

Due to its importance in the functioning of different ecosystems, dynamics of microbial biomass and its role in plant nutrition under different ecosystem conditions is of considerable significance (Tripathi and Singh, 2006).

Wetlands are subjected to changes in soil moisture as a result of both short-term seasonal climate variations and long-term changes in regional water resource management, both of which can modify the dynamics of ground and surface water inputs (Yu and Ehrenfeld, 2009).

Nitrogen cycling in wetland soils is thought to be highly sensitive to variations in soil moisture, which is a controlling variable affecting the redox potential of the soil. As wetland soils become increasingly anoxic, oxygen-dependent processes, in particular nitrification, are reduced or eliminated. At the same time, processes that require anoxic conditions, notably denitrification, may increase their rate (Pinay et al., 2002). Soil moisture in its turn varies with soil properties such as texture and organic matter content, which affect the water-holding capacity of the soils (Bruland and Richardson, 2004; Wendroth et al., 2006; Sleutel et al., 2008), and the balance between inputs and outputs in the water budget of the soil profile. Changes to water budgets can be critical in wetlands, where small alterations to inputs of precipitation, surface and groundwater can have large effects on the moisture status of the soil. Variations in climate, both seasonal and inter-annual, and long-term changes in regional water resource management can both cause change in the moisture content of wetland soils.

Material and methods

This experiment was pursued in the Nature Reserve (NR) Alúvium Žitavy. Located in the south-western part of Slovakia, in the cadastral territory of the town Hurbanovo and village Martovce. It is stretched along the lower stream Žitava, which is a part of the geomorphologic unit Podunajská nížina lowland. The NR with an acreage of 32.53 hectares was declared as a protected area in 1993, and its territory belongs to the 4th degree of protection. This protection has been declared for a woodland meadow with many diverse plant and animal species, including nesting birds. The area is characterized by a great diversity of habitats representing water vegetation, swamps, and floodplain forests. There are willow-poplar forests with rich scrub undergrowth providing shelters for many animal species. The protected plant species are *Nuphar luthea, Salix* sp., *Iris pseudacorus, Leucojum aestivum*, and several others. Much of the site area is flooded over the year, especially in spring. The fauna of the NR, is very rich in biodiversity. The ichtyofauna is represented by the species *Lepomis gibbosus, Perca fluviatilis, Carassius carassius*, and several others, the amphibians by the species *Bombina bombina, Hyla arborea, Rana esculenta*, and others, *Herpetofauna* by species of the genera *Lacerta* sp., *Natrix natrix*, and others, the birds by *Ardea purpura, Falco cherrug, Numenius Argue* and others and the mammals by *Ondatra zibethica, Martes martes, Talpa europaea, Vulpes vulpes*, and many others. Because the NR is directly adjacent to the surrounding agrocenoses, we can expect also them rich in animal species. The soils recorded in the Reserve are: Haplic Chernozems, Eutric Fluvisoils and Haplic Histosols, moderate to severe, the soil-forming substrate is mainly sand and gravel. The production potential of soils is high, the degree ploughing is up to 87.7%. The Nature Reserve is a part of the Podunajská nížina lowland, with the warmest in Slovakia, relatively homogenous climate with a mean annual temperature of 9.9 °C. Winters are mild and relatively windy, with little snow cover. The area has the longest growing season, allowing cultivation of even the most demanding technical and vegetable crops. The annual precipitation total ranges from 550 to 750 mm. The site is shaded by a narrow strip of riparian vegetation consisting of poplars and willows rich in scrub undergrowth, at the edges are present reed banks and overgrown bat. The water in the Žitava River is severely polluted. The riparian vegetation and plant scrub are good refuges for fauna, especially for avifauna, and they are also an important element in landscape-forming (Palatická, 2009).

The soil samples were collected over the whole two-year research period at four sampling sites in the Nature Reserve Alúvium Žitavy:

Sampling site 1 (SS1) – a dense grassland, by a sparse willow (*Salix* sp.) stand – collector can be cha-racterized as a typical wetland ecosystem.

Sampling site 2 (SS2) – a dense grassland, with dense vegetation consisting of phragmites (*Phragmites australis*) and willow (*Salix* sp.).

Sampling site 3 (SS3) – is covered with a dense grass vegetation, mostly flooded (during snow melting in spring intense rainfall episodes in summer when Žitava River flows over its bed).

Sampling site 4 (SS4) – a thick grassy vegetation, growing on the banks, consisting of cattail (*Typha latifolia*), phragmites (*Phragmites australis*), alder (*Alnus* sp.) and willow (*Salix* sp.).

The contents of inorganic forms of nitrogen (N-NO_3^- and N-NH_4^+) were measured in soil samples taken from sampling sites at the boundary of the Nature Reserve. The soil was sampled monthly from two depths (0.0–0.3 m and 0.3–0.6 m). In these samples, we determined the contents of inorganic nitrogen forms in 1% solution of potassium sulphate (K_2SO_4), with using the following methods:

- N-NO_3^- – colour method by acid phenoldihydrosulphide
- N-NH_4^+ – colour method by Nessler´s test solution.

The soil moisture content was determined by gravimetric method (in weight percent). For evaluation of pH value, a 1 mol dm^{-3} solution of potassium chloride was used.

The obtained values of inorganic nitrogen forms were presented in tables, figures and evaluated statistically. Because the data set did not show normal distribution, for statistical evaluation were used the Kruskal-Wallis test. Pearson's correlation coefficient was used to express the correlation between the chosen evaluated factors (Program Statgraphics Plus 5.0.1).

Results and discussion

The average content of ammonium nitrogen (N-NH_4^+) during the whole research period was 7.24 mg kg^{-1} (Table 1), with a standard deviation of 2.91 mg kg^{-1} (Table 2), which is higher than the value found in Žitavský luh by Kantor and Ondrišík (2005). The content of ammonium nitrogen was in the range 3.80–16.87 mg kg^{-1} (Table 1). Over the whole period, the coefficient of variance for the ammonium nitrogen was 40.18%, which is twice higher than those detected by Kantor and Ondrišík (2005). The statistical data for the content of ammonium nitrogen in the soil show a statistically high significant effect (significant level α = 0.01) (Table 3) of the year and the sampling date. The sampling depth and sampling site showed statistically significant effects, too.

In summary, the highest contents of N-NH_4^+ were determined in the year 2008 (16.87 mg kg^{-1}) (Table1). The Fig. 1 illustrates the dynamics of ammonium nitrogen in the two study years in the upper soil layer. We can see that the content of ammonium nitrogen had a decreasing character, but during the first year (2008), the decrease was more marked. The large decreases in soil N content after soil disturbances reported in this and other studies (Evans and Ehleringer, 1993) suggest that disturbance can modify the balance between N input and loss, causing a decrease in N storage within the

Table 1. Average contents of inorganic nitrogen forms over the whole research period (mg kg^{-1})

Monitored parameters		Average contents mg kg^{-1} of soil		
		N-NH_4^+	N-NO_3^-	N_{an}
Year	2008	9.16	1.76	10.93
	2009	5.33	2.30	7.63
Depth	0.0–0.3	7.43	2.33	9.76
	0.3–0.6	7.06	1.74	8.80
Sampling site	1	7.10	2.16	9.27
	2	7.36	2.32	9.68
	3	7.37	2.04	9.41
	4	7.14	1.62	8.76

Table 2. Basic statistical characteristic of measured variables (N-NO_3^-, N-NH_4^+, N_{an})

	Nitrogen form		
Statistical characteristic	N-NH_4^+	N-NO_3^-	N_{an}
Number of observation (n)	128	128	128
Average (x)	7.24	2.03	9.28
Standard deviation (s)	2.91067	1.26986	3.28249
Standard error (S_x)	0.25727	0.112241	0.290134
Minimum	3.80	0.44	4.71
Maximum	16.87	9.28	25.59
Coefficient of variation % (V)	40%	62%	35%

Table 3. Kruskal-Wallis analyses

Nitrogen form	Source of variability	Test statistics (K–W)	Significant level
N-NH_4^+	Depth	1.06	0.3022
	Sampling site	2.15	0.5424
	Sampling date	20.79	0.0041
	Year	76.72	0.0000
N-NO_3^-	Depth	20.31	0.0000
	Sampling site	10.52	0.0146
	Sampling date	11.05	0.1363
	Year	20.52	0.0000
N_{an}	Depth	6.85	0.0089
	Sampling site	3.61	0.3072
	Sampling date	3.16	0.0000
	Year	39.99	0.0000

soil (Evans and Belnap, 1999).The average content at the first depth (surface layer) was 9.50 mg kg^{-1}, whereas at the second depth it was 8.86 mg kg^{-1} (Fig. 2).

In terms of sampling sites, the content of ammonium nitrogen ranged from 7.10–7.37 mg kg^{-1}. The highest content was observed in the sampling site 3, the lowest in SS 1. The same trend was also found in Žitavský luh (Kantor and Ondrišík, 2005). These authors detected the highest concentrations of ammonium nitrogen in sample sites representing a typical wetland ecosystem and the lowest in sample sites representing meadow ecosystems.

Significantly dropped contents of ammonium nitrogen were recorded on the first four sampling dates in 2008 at both soil depths.

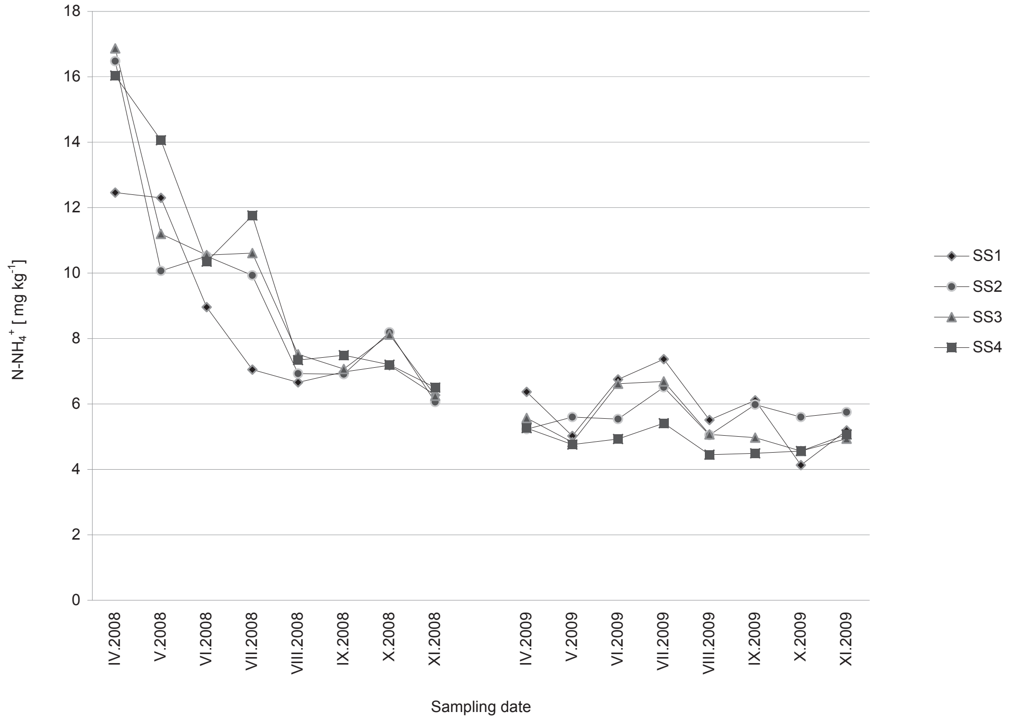


Fig. 1. Dynamics of ammonium nitrogen at a depth of 0.0–0.3 m in the years 2008 and 2009

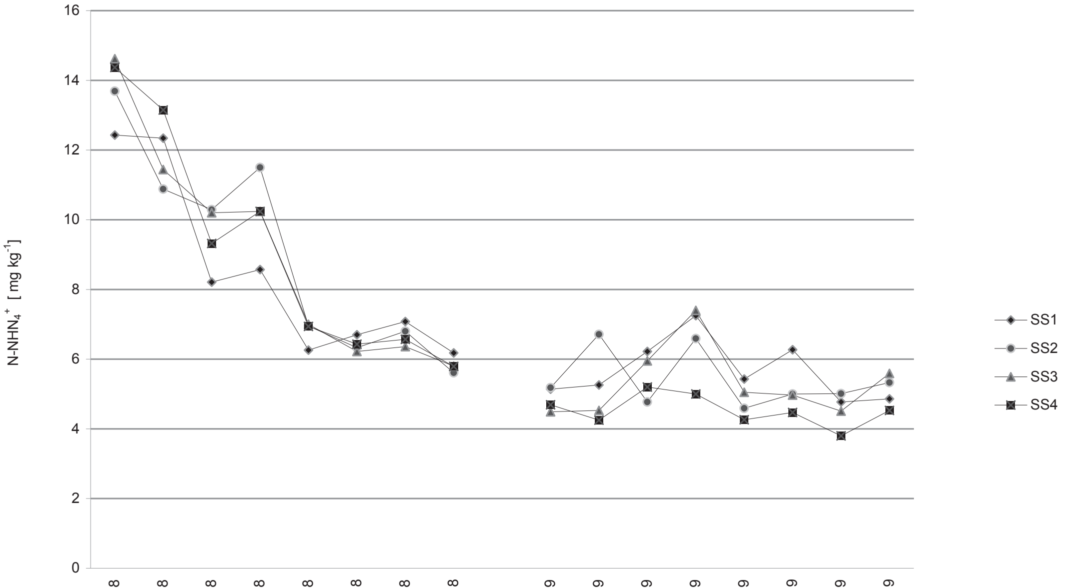


Fig. 2. Dynamics of ammonium nitrogen at a depth of 0.3–0.6 m in the years 2008 and 2009

In comparison with the ammonium nitrogen, the nitrate nitrogen showed slower dynamics over the whole research period. The average content of nitrate nitrogen over the whole research period (2008 and 2009) was 2.03 ± 1.27 mg kg^{-1} (Table 1, Table 2). This low concentration does not mean a threat to the quality either of groundwater or of surface water. Its value is even lower than the one obtained by Kantor and Ondrišík (2005) in the wetland Žitavský luh. Gilliam et al. (1999) report that the inorganic N forms of nitrogen were extractable almost equally to NO$_3$ and NH$_4$ in old field soils. The anaerobic conditions in the swamp soils, however, prevent nitrification. Pinelands soils, including upland and mineral wetland soils, in general show very low or zero rates of net nitrification, and no or in very low concentrations nitrates in soil pore water (Ehrenfeld et al., 1997a, b).

The interval in both years was 0.44–9.28 mg kg^{-1} (Table 1). For nitrate nitrogen was found a higher coefficient of variance (62.43%) than for ammonium nitrogen.

This higher variation coefficient values were connected with marked nitrate nitrogen – see Fig. 6. The exceptions were observed in case of the first sampling date, the second sampling site, at the both sampling depths. The content of nitrate nitrogen on the first sampling date was 9.11 mg kg^{-1} (the first depth 0.0–0.3 m) (Fig. 3) and 9.28 mg kg^{-1} (the second depth 0.3–0.6 m) (Fig. 4). Many observations of drained wetlands confirm increases in both soluble inorganic N content and N process rates (Regina et al., 1996, 1999; Freeman et al., 1997; Olde et al., 2002; Tiemeyer et al., 2007). Similar responses were observed in riparian wetlands drying out during summer months (Bechtold and Naiman, 2006). However, Regina et al. (1996) found that there were differences in effects of drainage on nitrate production between minerotrophic fens and ombrotrophic bogs, suggesting that soil characteristics control the response of wetland soils to drying. In a series of studies, Bridgham (1995) and colleagues (Updegraff et al., 1995; Bridgham et al., 1998) show that many types of histosols had higher rates of N mineralization and nitrification when they were incubated under aerobic conditions than in case of anaerobic conditions. However, the authors found that the relative change in nitrification rate, particularly the share of nitrification in proportion to the total net mineralization, varied considerably among the soil types, reflecting differences in the substrate quality. In mineral wetland soils, N mineralization reaches maximum at intermediate levels of soil moisture (57–78% waterfilled pore space) (Sleutel et al., 2008); the precise values vary with soil texture and soil organic matter amount.

More variability was also observed during the second year (2009) in all sampling sites (Fig. 4). The highest content of nitrate nitrogen was found on the first sampling date in the first sampling site (5.8 mg kg^{-1}), and a more marked increase was identified on four sampling dates (IV.2009, V.2009, VI.2009, VII.2009) at the second sampling depth. In the case of nitrate nitrogen, statistically high significant effect was obtained for the year and sampling depth. Statistical significant effect (significant level $\alpha = 0.05$) was found only in the sampling site (Table 3).

As for sampling sites, the content of ammonium nitrogen ranged between 1.62–2.32 mg kg^{-1}. The highest content was found in the sampling site 2, the lowest in SS 4.

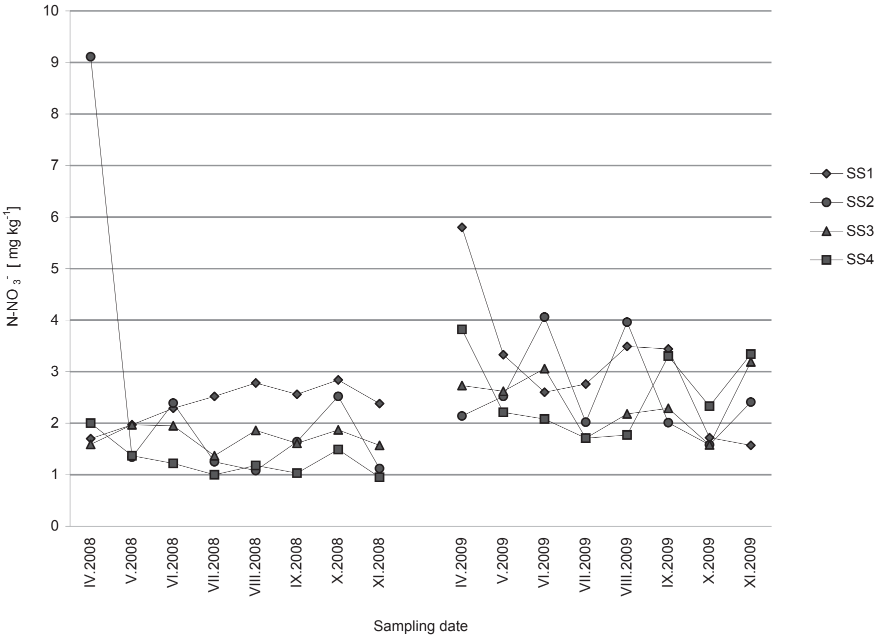


Fig. 3. Dynamics of nitrate nitrogen in depth of 0.0–0.3 m in the years 2008 and 2009

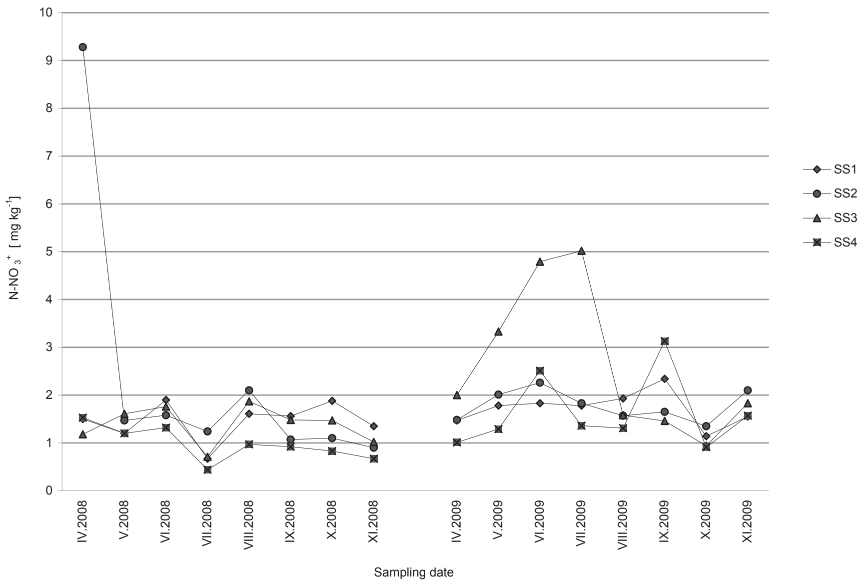


Fig. 4. Dynamics of nitrate nitrogen in depth of 0.3–0.6 m in the years 2008 and 2009

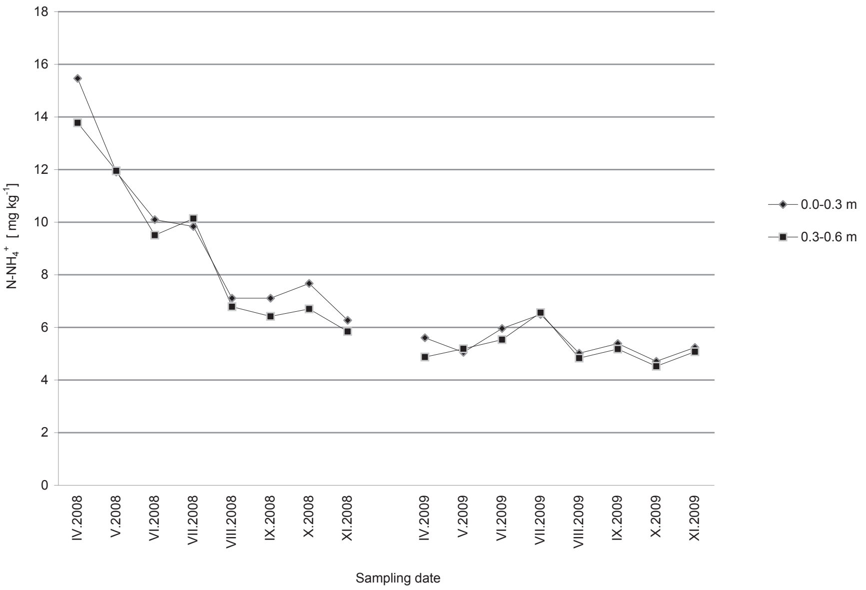


Fig. 5. Dynamics of ammonium nitrogen at depths 0.0–0.3 m and 0.3–0.6 m in the years 2008 and 2009

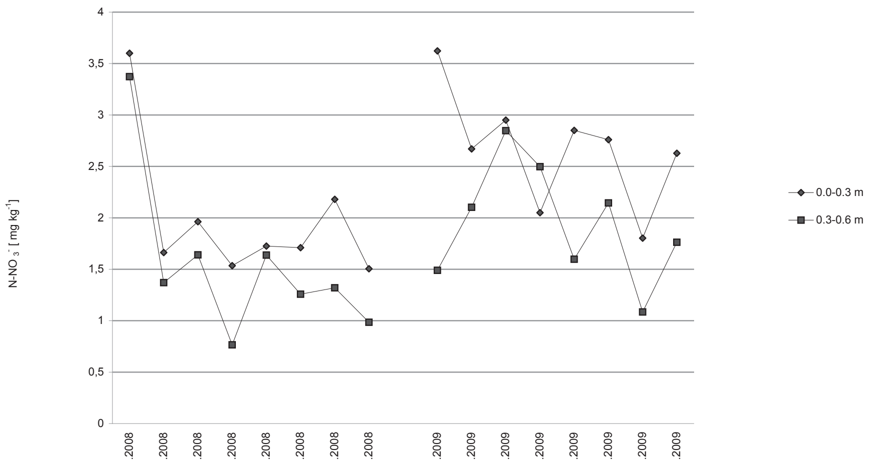


Fig. 6. Dynamics of nitrate nitrogen at depths 0.0–0.3 m and 0.3–0.6 m in the years 2008 and 2009

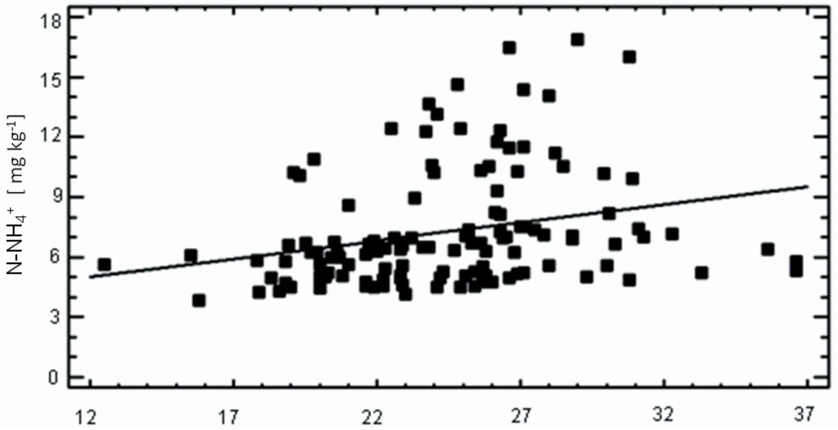
The comparison between the two nitrogen forms (ammonium and nitrate) shows that the values ammonium nitrogen were almost the same at the both sampling depths (Fig. 5); on the other hand, there were some differences in the contents of nitrate nitrogen between the depths (Fig. 6). The average value of ammonium nitrogen at the first depth was 7.43 mg kg^{-1} and at the second depth 7.06 mg kg^{-1}. In the case of nitrate nitrogen, the average nitrogen content value at the first depth was 2.33 mg kg^{-1}, at the second depth 1.74 mg kg^{-1}.

In the Table 2 we can see that the average value of N-NH$_4^+$ content (7.24 mg kg^{-1}) was higher than the content of the N-NO$_3^-$ (2.03 mg kg^{-1}). Gilliam et al. (1998) found out that anaerobic conditions in the swamp soils, prevent nitrification; consequently, in the swamp soils there was only a little amount of nitrogen in the form of NO$_3^-$ and more than 98% of extractable nitrogen was present in the form of NH$_4^+$.

The next statistic indicator – the Pearson´s correlation coefficient indicated only very weak relations between N-NO$_3^-$ and N-NH$_4^+$.

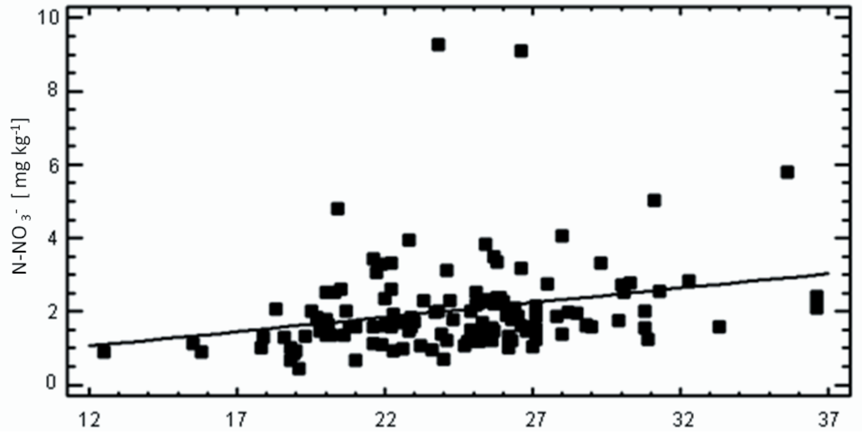
Table 4. Pearson´s correlation coefficients with fitting P-values

Pairs	Pearson´s correlation coefficient	P-value
N$_{an}$ – N-NO$_3^+$	0.4696	0.0000
N$_{an}$ – N-NH$_4^+$	0.9228	0.0000
N$_{an}$ – moisture	0.3322	0.0001
N-NH$_4^+$ – moisture	0.2610	0.0029
N-NO$_3^-$ – moisture	0.2604	0.0030



Moisture %

Fig. 7. Dependence of N-NH$_4^+$ on soil moisture



Moisture %

Fig. 8. Dependence of N-NO$_3^-$ on soil moisture

Table 4 shows Pearson´s correlation coefficient between that pairs of variables with P-value lower than 0.05. P-values below 0.05 indicate statistically significant non-zero correlations at the 95% confidence level. The values of Pearson´s coefficients for correlation between moisture and N-NH_4^+ (0.2610) and moisture and N-NO_3^- (0.2604) show a week correlation even for the P-value lower than 0.01. The graphical interpretations are in Figs 7 and 8.

Conclusions

During the years 2008–2009 we monitored contents and dynamics of inorganic N forms in the Nature Reserve Alúvium Žitavy. From the acquired results, we can draw the following conclusions:

- The content of the ammonium nitrogen ranged between 3.80–16.87 mg kg^{-1} with an average of 7.24 mg kg^{-1}. Higher concentrations were observed in the first year (2008).
- The most dominant inorganic form of nitrogen was ammonium, the proportion of the bulk inorganic nitrogen was 78.08%.
- The dynamics of the ammonium nitrogen during the year 2008 was decreasing; in the second year, it has been somewhat stabilised.
- The highest content of ammonium nitrogen was measured in sampling site 3 (7.36 mg kg^{-1}), the lowest in sampling site 1 (7.10 mg kg^{-1}).
- The dynamics of nitrate nitrogen during the two years was different from the dynamics of ammonium nitrogen. The higher concentration (2.30 mg kg^{-1}) was found in the second year.
- The highest content of nitrate nitrogen was measured in sampling site 2 (2.31 mg kg^{-1}), the lowest in sampling site 4 (1.62 mg kg^{-1}).

The important information is that the nitrate nitrogen concentrations maintain low (especially in depth from 0.3 to 0.6 m) and pose no risk of pollution to either surface water or groundwater.

Acknowledgement

This research was supported by the grant project VEGA 1/0275/08 „Štúdium abiotických a biotických zložiek Prírodnej rezervácie Alúvium Žitavy a jej význam pre zachovanie biodiverzity poľnohospodárskej krajiny (Study of abiotic and biotic components of the Nature Reserve Alúvium Žitavy and its importance for preserving biodiversity of agricultural land)“.

References

BECHTOLD, S.J., NAIMAN, R.J. 2006. Soil texture and nitrogen mineralization potential across a riparian toposequence in a semi-arid savanna. *Soil Biol. and Biochem.*, 38: 1318–1325.

BRIDGHAM, S.D., UPDEGRAFF, K., PASTOR, J. 1998. Carbon, nitrogen, and phosphorus mineralization in northern wetlands. *Ecology*, 79: 1545–1561.

BRULAND, G.L., RICHARDSON, C.J. 2004. Hydrologic gradients and topsoil additions affect soil properties of Virginia created wetlands. *Soil Sci. Soc. Amer. J.*, 68: 2069–2077.

DINNES, D.L., DOUGGLAS, L.K., JAYNES, D.B., KASPAR, T.C., HATFILED, J.L., COLVIN, T.S., CAMBARDELLA, C.A. 2002. Nitrogen managment strategies to reduce nitrate leaching in tile-drained midwestern soil. *Agron. J.*, 94:153–171.

EHRENFELD, J.G., HAN, X., PARSONS, W.F.J., ZHU, W. 1997a. On the nature of environmental gradients: temporal and spatial variability of soils and vegetation in the New Jersey Pinelands. *J. Ecol.*, 85: 785–798.

EHRENFELD, J.G., PARSONS, W.F.J., HAN, X., PARMELEE, R.W., ZHU, W. 1997b. Live and dead roots in forest soil horizons: contrasting effects on nitrogen dynamics. *Ecology*, 78: 348–362.

EVANS, R. D., BELNAP, J. 1999. Long-term consequences of disturbance on nitrogen dynamics in an arid ecosystem. *Ecology,* 80(1):150-160.

EVANS, R. D., EHLERINGER,J.R. 1993. A break in the nitrogen cycle of aridlands: evidence from δ^{p15}N of soils. *Oecologia,* 94: 314–317.

FREEMAN, C., LOCK, M.A., HUGHES, S., REYNOLDS, B., HUDSON, J.A. 1997. Nitrous oxide emissions and the use of wetlands for water quality amelioration. *Envir. Sci. Techn.*, 31: 2438–2440.

GILLIAM, F.S., MAY, J.D., FISHER, M.A., EVANS, D.K. 1999. Short-term changes in soil nutrients during wetland creation. *Wetlands Ecol. Mgmt*, 6: 203–208.

KANTOR, M., ONDRIŠÍK, P. 2005. Dynamics of inorganic forms of nitrogen in soils of the Nature Reserve Žitavský Luh. *Folia oecol.*, 32: 15–24.

OLDE, V. H., DAVIDSSON, T.E., KIEHL, K., LEONARDSON, L. 2002. Impact of drying and re-wetting on N, P and K dynamics in a wetland soil. *Pl. and Soil,* 243: 119–130.

PALATICKÁ, A. 2009. *Monitorovanie a hodnotenie kvality vody v Prírodnej rezervácii Alúvium Žitavy* [Monitoring and evaluation of water quality in the Nature Reserve Alúvium Žitavy]. PhD thesis. Nitra: Slovak University of Agriculture, Faculty of Agrobiology and Food Resources. 247 p.

PINAY, G., CLEMENT, J.C., NAIMAN, R.J. 2002. Basic principles and ecological consequences of changing water regimes of nitrogen cycling in fluvial systems. *Envir. Mgmt*, 30: 481–491.

REGINA, K., SILVOLA, J., MARTIKAINEN, P.J., 1999. Short-term effects of changing water table on N_2O fluxes from peat monoliths from natural and drained boreal peatlands. *Glob. Change Biol.*, 5: 183–189.

REGINA, K., NYKANEN, H., SILVOLA, J., MARTIKAINEN, P.J., 1996. Fluxes of nitrous oxide from boreal peatlands as affected by peatland type, water table level and nitrification capacity. *Biogeochem.*, 35: 401–418.

Sleutel, S., Moeskops, B., Huybrechts,W., Vandenbossche, A., Salomez, J., De Bolle, S., Buchan, D., De Neve, S., 2008. Modeling soil moisture effects on net nitrogen mineralization in loamy wetland soils. *Wetlands*, 28: 724–734.

Tiemeyer, B., Frings, J., Kahle, P., Kohne, S., Lennartz, B., 2007. A comprehensive study of nutrient losses, soil properties and groundwater concentrations in a degraded peatland used as an intensive meadow – implications for rewetting. *J. Hydrol.*, 345: 80–101.

Tripathi, N., Singh, R. S. 2006. Cultivation impacts nitrogen transformation in Indian forest ecosystems. *Nutr. Cycl. Agroecosys.,* 77: 233–243.

Updegraff, K., Bridgham, S.D., Pastor, J., Johnston, C.A., 1995. Environmental and substrate controls over carbon and nitrogen mineralization in northern wetlands. *Ecol. Appl.*, 5: 151–163.

Yu, S., Ehrenfeld, J.G. 2009. The effects of changes in soil moisture on nitrogen cycling in acid wetland types of the New Jersey Pinelands (USA). *Soil Biol. and Biochem.*, 41: 2394–2405.

Dynamika anorganických foriem dusíka v pôde Prírodnej rezervácie Alúvium Žitavy

Súhrn

Vzorky pôdy z Prírodnej rezervácie Alúvium Žitavy boli odoberané počas dvoch rokov 2008–2009 a následne bola vyhodnotená dynamika anorganických foriem dusíka. Sledovali sme zmeny anorganických foriem dusíka v závislosti od hĺbky odberu pôdnych vzoriek, pôdnej vlhkosti, dátumu odberu a miesta odberu pôdnych vzoriek. Po porovnaní obsahov N_{min} počas celého výskumného obdobia sme zistili, že vyššie hodnoty boli v prvom roku (2008). Amónny dusík sa pohyboval v hodnotách 3,80–16,87 mg kg^{-1} a jeho priemer v sledovanom období bol 7,24 mg kg^{-1}, pričom v roku 2008 bol jeho obsah vyšší ako v roku 2009. Dusičnanový dusík mal opačnú tendenciu. Hodnoty dusičnanového dusíku boli v rozsahu 0,44–9,28 mg kg^{-1} s priemerom 2,03 mg kg^{-1} s vyššími hodnotami v roku 2009.

Štatisticky vysoko preukazný vplyv na obsah amónneho dusíka mali rok a dátum odberu. Na obsah dusičnanového dusíka štatisticky vysoko preukazne vplývala hĺbka, rok a miesto odberu.

Vzhľadom na vysoké variačné koeficienty neboli zistené žiadne korelácie medzi vlhkosťou pôdy a obsahmi sledovaných foriem anorganického dusíka.

Nízke hodnoty dusičnanového dusíka neznamenajú riziko znečistenia podzemných ani povrchových vôd.

Received February 11, 2010
Accepted June 17, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Occurrence of dry periods in oak stands and their effects on soil water supply

Ladislav Tužinský[1], Jozef Ištoňa[2]
[1]Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen,
T. G. Masaryka 24, SK-960 53 Zvolen, Slovakia, E-mail: tuzinsky@vsld.tuzvo.sk
[2]National Forestry Institute, T. G. Masaryka 22, SK-96092 Zvolen, Slovakia, E-mail: jozef.istona@nlcsk.org

Abstract
Tužinský, L., Ištoňa, J. 2010. Occurrence of dry periods in oak stands and their effects on soil water supply. *Folia oecol.,* 37: 95–102.

The presented paper deals with the impact of long lasting dry periods on the water regime in oak forest stands growing in lowlands. Cycles of low or insufficient available water supply reflect changes to soil moisture conditions that may cause physiological weakening of the trees. The research was carried out on the research plots in Čifáre, during years 1984–2007. Soil samples were taken from the depth of 0–20 and 0–100 cm. Soil water dynamics was observed especially in the extremely dry years 2000 and 2003. The results have confirmed the soil desiccation beginning in autumn. Dry periods in the growing season are characterized by an semiarid and arid soil moisture interval in the upper 20 cm soil layer. Here, also the hardly accessible or even inaccessible for plants water was observed. Across the whole physiological soil profile, the semiarid interval with soil moisture content ranging between the point of diminished availability (PDA) and the wilting point (WP) was dominant.

Key words
climatic changes, drought, hydrologic thresholds, oak forest stands, soil water

Introduction

Climatic measurements performed in Slovakia over the last 100 years show an increasing trend in the mean annual air temperature – by 1.1 °C. At the same time, there has been recorded a decrease in annual precipitation totals – by 5.6% on average, with the values lower in southern areas (Lapin et al., 2001, Lapin in Balajka et al., 2005). Minďáš and Škvarenina (2003) suggest that the precipitation deficiency can negatively influence soil moisture conditions, health condition and production of forest woody plants not only in ecosystems situated in the lower lower vertical forest vegetation zones (vfvz) with dominant oaks (1st–3rd vfvz) but also in forest associations with prevailing beech (4th–6th vfvz) or in even higher vertical forest vegetation zones (vfvz). The influence of the climatic factors on diameter increment in oak trees is described in more detail in the paper Pajtík and ištoňa (2003). Ištoňa and Čaboun (2006, 2007) observed the forest soil water regime in the 1st–5th vfvz, and found out that the drought risk did not concern only oak forest stands in lowlands and uplands but also beech forest stands in the 2nd–4th vfvz. This threat was especially critical in case of intensive evapo-transpiration and extended dry periods (Soroková 2001).

In relation to the climatic scenarios for Slovakia, air temperature and evapo-transpiration are expected to increase continually. For both lowlands and uplands, this can mean significantly decreased soil water supply during the growing seasons, followed by severe droughts causing physiological damage to the woody plants.

Our main objective was to analyse selected extreme long lasting dry periods in the years 1984–2007 and their effects on the soil moisture dynamics on two model research plots in Čifáre.

Material and methods

The paper presents analyses of hydro-climatic cycles in forest soils at a research site situated in the Kozmálovské hills. The experimental data were assembled from two research plots belonging to the area of the Forest Administration Čifáre, OLZ (Branch Forest Enterprise) Levice.

The discussed research plots belong to the warm climatic area with 60–70 summer days. The mean annual temperature is 9 °C, over the growing season 16 °C, the mean annual precipitation total is 560 mm, the total precipitation amount in the growing season 290 mm (Table 1). The values in Table 1 have been provided by the Slovak Hydrometeorological Institute in Bratislava, the Mochovce observatory.

The research plots are situated in the 1st vfvz, in the Carpineto-Quercetum forest type group (Zlatník, 1959, 1976). The forest cover on the first plot consists exclusively from sessile oak [*Quercus petraea* (Mattusch.) Liebl.], approx. 100 years of age. The second research plot is covered by common oak (*Quercus cerris* L.) aged 85 years. The canopy density on both plots is 90%, the stocking density is 0.7. The cover of bush and herb layer with grass makes 90%.

Hydro-physical soil characteristics as well as the values of hydrologic thresholds on the two plots are identical in typology and materials – see Table 2 (Tužinský, 2004).

The soil type is a loamy luvisol, with clay-loam in deeper layers, slight marks of gleying, medium texture differentiation, very acidic to acidic, strongly leached around the oak root systems, with low humus supply. The parent rock material is silt loam, the aeration and hydration at the depth of 40 cm is worsened. The soil is physiologically deep, richer root systems are at the depth of 45–50 cm, sporadically even deeper.

The actual soil water supply was observed at intervals of 14 or 10 days. Its values were determined with using the gravimetrical method. Soil samples were taken with a soil bore, in 3–5 repliques from each 10 cm layer up to the depth of 100 cm. The results were presented in weight % or in volume %.

The amount of water available for plants was calculated as immediate soil water supply subtracted by "dead" water. The limit between the physiologically available and the "dead" water was determined as the limit for WP. The supply of available water (Table 3) was calculated according to Kutílek (1966), and the

Table 1. Main climatic variables

Air temperature in °C, Nový Tekov 1931–1960													
XI.	XII.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	Year	GS
4.7	0.1	–2.5	–1.5	4.2	10.2	15.0	18.1	20.3	19.5	15.6	9.7	9.5	16.4
Precipitation in mm, Čifáre 1931–1960													
57	46	38	39	35	35	53	62	56	52	33	48	554	291

GS, growing season

Table 2. Hydro-physical soil characteristics

Characteristic	Soil depth in cm					∑ mm
	0–10	20–30	40–50	70–80	90–100	0–100
Bulk density [g cm^{-3}]	2.41	2.49	2.54	2.57	2.58	–
Weight volume [g cm^{-3}]	1.31	1.40	1.45	1.49	1.52	–
Porosity [vol. %]	50.3	47.8	43.5	41.8	41.6	–
MCC [vol. %][1]	36.7	36.0	33.8	32.8	30.5	334.2
PDA [vol. %][2]	25.3	25.7	25.3	23.5	24.0	246.1
WP [vol. %][3]	15.5	15.4	15.3	15.2	15.1	150.5

[1]maximal capillary capacity, [2]point of diminished water availability, [3]wilting point

Table 3. Available water supply (according to Kutílek, 1966)

Available water supply			
Soil layer 0–20 cm		Soil layer 0–100 cm	
Good	>40 mm	Very good	>160 mm
Sufficient	20–40	Good	130–160
Insufficient	<20	Sufficient	90–130
		Low	60–90
		Very low	<60

ecological classification of the soil water regime was made according to the same author (Kutílek, 1971).

Results and discussion

The term "drought" represents in general water insufficiency in soils, plants and atmosphere. Water insufficiency in soils can result in water supply dropped below the wilting point (WP). The recent measurements show that the drought periods in growing seasons are prolonged and more intensive with the progressing climatic change.

Most changes in soil hydro-physical characteristics are observed over the whole year, especially in lowlands and uplands with oak associations belonging in the 1st and the 2nd vfvz, in which the soil drying related to the temperature and precipitation regime is characterized by its dynamics. The Fig. 1 and Fig. 2 show that there were small intervals with sufficient water supply even in the growing seasons of the driest years. Except of these intervals, water supply in the growing season was insufficient. Winter is the season of soil moisture accumulation, hence the moisture levels at the beginning of the growing season are in general good. The upper 20 cm layer of the soil profile is supplied with water especially during the snow melting and the soil de-freezing. In this period, when the day temperatures do not exceed 20 °C, the capillary mobile water is present across the whole physiological soil profile (0–100 cm), as good and very good available water supply (>130 mm). In such a way, the sufficient water amount in the soil for the following growing season is guaranteed also in case of insufficient precipitation totals.

In extremely dry years, the soil drying off starts already in autumn. This is well demonstrated in Fig. 1 and Fig. 2 showing the dynamics of the soil water supply in the extremely dry year 2000.

It is necessary to add that extremely dry years are accompanied by a significant positive deviation in the average temperature not only in autumn but also in some winter months, furthermore by occurrence of very poor in precipitation or even dry seasons lasting for several weeks or months, often accompanied by windy weather that accelerates the early drought start.

During the growing season, the soil water supply is mainly influenced by the vegetation (except for precipitation totals). Output components of the water balance represent interception losses being 26% of the precipitation totals. Precipitation less than 1 mm evaporates. The amount of precipitation intercepted by herb and grass layer varies from 9 to 38%. Water infiltration to the soil reaches higher values only during winter accumulation period (20–30% of precipitation totals), while during the growing season it does not exceed 10%. In the second half of the growing season, we can consider infiltration as a negligible component. The infiltration is also connected with the root system influence directly increasing the soil porosity. Very significant are active roots growing in deeper soil layers which play an important role especially during dry summer season when the upper soil layers are strongly desiccated (Tužinský, 2004).

The most considerable changes in the soil water content can be observed in the upper soil layers. Here the soil moisture varies from the category of moist soil to the WP. In dry seasons, the soil moisture condition is characterized by insufficient supply of available water, WP is not an exception.

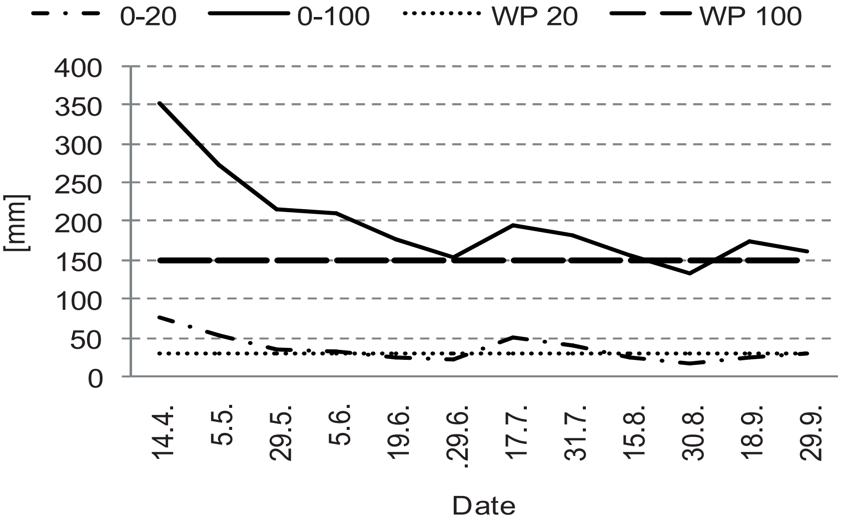


Fig. 1. Dynamics of soil water content in layers 0–20 and 0–100 cm during the vegetation period 2000. The figure includes the limit values for each layer (wilting point).

Water requirements on the water balance output are usually higher than the precipitation totals during the growing season. In dry seasons with no precipitation and high air temperature, the water requirements for evapotranspiration are higher than 5 mm day^{-1} (Tužinský, 1999, 2004), representing a very high day values. Such water requirements result in a fast loss of available soil water. The decrease in water amount is visible even in deeper layers of the soil with active roots presence (0–40 cm). In the upper soil layer up to 20 cm, which is mostly threatened by drought, often a zero available water supply can be observed (Table 4). In the deeper soil layers (>60 cm), the water amount varies between the points PDA and WP. After longer lasting dry periods, a very low supply of available water was observed across the whole soil physiological profile (<60 mm).

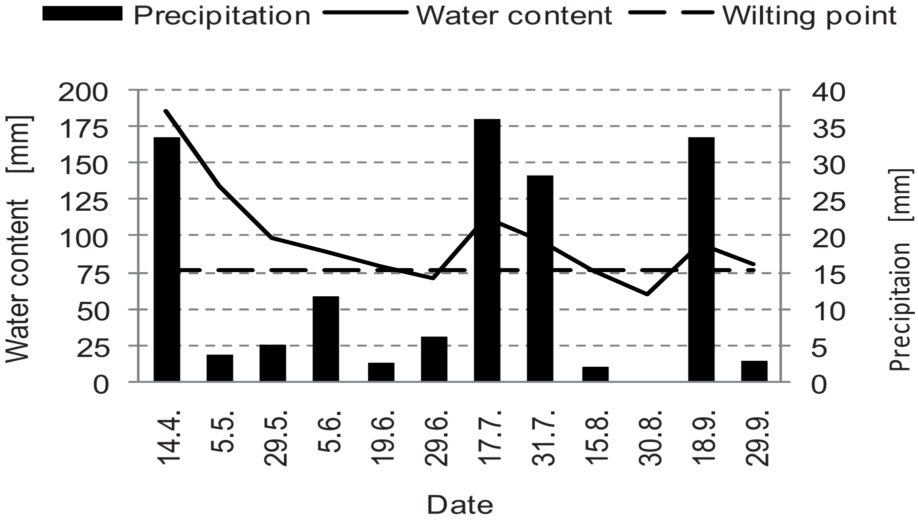


Fig. 2. Dynamics of precipitation amount and soil water content in the layer 0–50 during the vegetation period 2000. The figure includes the limit values for this layer (wilting point).

Table 4. Water supply in the dry periods of the growing seasons (Čifáre)

Season		Water supply [mm]		Available water [mm]		Intervals of the soil water Available water	
		0–20 cm	0–100 cm	0–20 cm	0–100 cm	0–20 cm	0–100 cm
1988	1. 7.	40.1	242.4	10.9	91.9	SA/IS	SA/S
	31. 7.	21.1	169.2	0	18.7	A/0	SA/VL
1988	5. 8.	40.2	200.7	11	50.2	SA/IS	SA/VL
	20. 8.	19.1	148.7	0	0	A/0	SA/VL
1989	1. 9.	43.5	181.4	13.8	30.9	SA/IS	SA/VL
	30. 9.	26.9	164.8	0	14.3	SA/0	SA/VL
1990	11. 7.	68.1	223.9	38.9	73.4	SU/S	SA/L
	31. 8.	21.9	159.9	0	9.4	A/0	SA/VL
1991	2. 8.	31.6	216.1	2.4	65.6	SA/IS	SA/L
	16. 9.	18.1	156.1	0	5.6	A/0	SA/VL
1992	14. 7.	22.6	231.9	0	71.4	A/0	SA/L
	31. 8.	18.1	169.1	0	18.6	A/0	SA/VL
1993	28. 7.	24.4	206.4	0	55.9	SA/0	SA/VL
	22. 8.	19.7	161.7	0	11.2	A/0	SA/VL
1994	14. 7.	28.7	232.9	0	82.4	SA/0	SA/L
	11. 8.	21.7	156.9	0	6.4	A/0	SA/VL

Table 4. Continued

Season		Water supply [mm]		Available water [mm]		Intervals of the soil water Available water	
		0–20 cm	0–100 cm	0–20 cm	0–100 cm	0–20 cm	0–100 cm
1995	3. 7.	53.7	291.8	24.5	141.3	SA/S	SA/G
	21. 8.	23.6	179.4	0	28.9	SA/0	SA/VL
1997	22. 7.	46.1	217.9	16.9	67.4	SA/IS	SA/L
	30. 9.	29.1	168.2	0	17.7	SA/0	SA/VL
1999	23. 7.	78.5	345.9	49.3	195.4	SU/G	U/VG
	15. 8.	48.9	214.8	19.7	64.3	SA/IS	SA/L
1999	17. 8.	48.9	214.8	19.7	64.3	SA/IS	SA/L
	30. 9.	18.9	122.4	0	0	A/0	SA/0
2000	1. 8.	37.7	163.3	8.5	12.8	SA/IS	SA/VL
	15. 9.	20.1	127.2	0	0	A/0	SA/0
2001	1. 6.	39.3	217.5	10.1	67.0	SA/IS	SA/L
	30. 6.	23.1	141.3	0	0	SA/0	SA/0
2002	17. 6.	34.9	241.2	0	90.7	SA/0	SA/S
	12. 7.	23.1	159.1	0	8.6	A/0	SA/VL
2003	1. 8.	36.2	207.3	7	56.8	SA/IS	SA/VL
	28. 8.	18.7	163.2	0	12.7	A/0	SA/VL
2004	27. 8.	28.1	142.7	0	0	SA/0	SA/0
	21. 9.	15.3	132.3	0	0	A/0	SA/0
2006	3. 7.	37.6	224.3	8.4	73.8	SA/IS	SA/L
	28.7.	21.4	148.7	0	0	A	SA

Intervals of the soil water:
A, arid interval (<WP)
SA, semiarid interval (PLA–WP)
SU, semiuvidic interval (MCC–PLA)
U, uvidic interval (>MCC)

Available water: 0–20 cm
G, good
S, sufficient
IS, insufficient

0–100 cm
VG, very good
G, good
S, sufficient
L, low
VL, very low

Table 4 shows dry periods with no precipitation or with precipitation totals lower than 5 mm (except for the 1st ten-day period of July 1990 and the 2nd ten-day period of July 1999). Our observations in Čifáre allow us to declare that such precipitation totals are not significant for supplying the soil with water in dry periods. This table also shows that in the upper 20 cm soil layer, a total use of the available water can be observed. Such soil moisture condition results in plant wilting, ground vegetation dieback, bushes wasting as well as tree growth processes slowed down or even terminated (Pajtík and Ištoňa, 2003).

The ability of forest soils to provide sufficient water amounts depends on their infiltration, percolation, retention, and retarding properties. Forest soil water regime is also a result of atmospheric water presence and on transforming effects of forest ecosystem on mutual processes. In our case, the hydro-physical soil properties in the oak stand are very favorable in the upper and middle layers of the soil profile. The available water supply decrease in this physiological soil profile can be explained as worsening of the climatic conditions.

The infiltration represents the main source of the soil water on our research plot. According to the soil physiological profile structure and texture, the soil water redistribution is very variable. Other soil profiles, with less skeleton and low water holding capacity, especially in the oak zone of the 1st and 2nd vfvz (mostly on steep slopes of andesite agglomerates), are even drier in their whole (Ištoňa and Čaboun, 2006, 2007).

Luvisols and cambisols are characteristic with their horizons alternating according to different physical properties. From the hydro-physical point of view, the illuvial horizon is more compact and thus less permeable for the water. On the other hand, in such horizon drying off takes longer. Thus, in seasons with sufficient precipitation totals, the water supply from the upper layers is limited, and in dry periods, the water transport from the deeper soil layers is slowed by interruption of the upper horizons.

According to the moisture condition, its duration and the soil moisture stratification (Kutílek, 1971) semiarid and arid soil moisture intervals with capillary water less mobile or even immobile were observed in the upper 20 cm soil layer during dry periods. The category of capillary mobile water and for plants available water was reached only for a short period of time after rich precipitation.

The semiarid interval with the soil moisture content between PDA and WP dominates across the whole physiological profile and during dry periods of the growing season. In this case, the water mobility is reduced; the osmotic pressure of soil solution increases, and thus water becomes less available for plants. In the critically dry period with insufficient water supply the water amount approaches the lower limit of the WP. Significant increase in the soil moisture in the whole physiological profile was observed only after a longer lasting precipitation activity.

Forest represents biological systems influencing the water circulation more than other plant associations – because a forest's influence on water balance components (interception, transpiration, seepage, runoff, etc.) is complex. Also the soil texture and structure affect not only soil water mobility but also the water retardation ability.

Very diverse is the relation between forest woody plants and water regime. Each tree has its own biorhythm depending on the site conditions, supply of accessible nutrients and available water supply. Spruce with its shallow root system draws water from upper soil layers, beech mostly from middle layers and oak always from the whole physiological profile. As for beech ecosystems, their more favourable moist conditions can be explained by increased water uptake from the stemflow.

The herb vegetation draws water mostly from the upper soil layers, from deeper ones, only after longer lasting dry periods.

Ištoňa and Čaboun (2006, 2007) observing the forest soil water regime (1st–5th vfvz) found out that increasing soil water content with decreasing water availability reflects the high water consumption for evapotranspiration, especially from June (lower vfvz) to July (higher vfvz). The lowest values are reached towards the end of June or July and they persist up to August and September, sometimes even longer (e.g. autumn of 2005 and 2006). The lowest values of the soil moisture content were observed at the end of August and at the beginning of September, especially in the forest type groups CQ and FQ in which the soil moisture dropped below 10 weight percent corresponding to a decrease below the WP critical value. Similarly, in these months, the soil moisture reached its minimum in the forest type groups Fp (the 3rd vfvz) and FT (the 4th vfvz). Here, the soil moisture content decreased below 20 % representing a decreased water availability. The data obtained in the locality Mláčik – forest type group FAc (the 5th vfvz) – show that even in these sites, the soil moisture decreases in summer, although the 25–40% soil water content is still considered as good.

Tužinský (2007) carried out long lasting monitorings of soil water content, moisture presence duration and moisture stratification (ecological classification of the soil moisture). Based on the obtained results, he declares significant changes in soil moisture dynamics and in the available water supply over the past 35 years. These changes can be documented by a more frequent presence of soil moisture cycles with a low or even insufficient available water supply, furthermore by the presence of dry periods that significantly contribute to the worsened health condition of forests even in higher forest vegetation zones.

Conclusions

A typical hydrological year consists of two seasons. The winter represents mostly the accumulation season – which means that the soil water supply is mostly good. This secures a good start of the growing season for the vegetation. During the growing season, especially in the lower forest vegetation zones, the water output dominates over the water uptake resulting in gradual water supply decrease and the drought. In case of longer lasting dry periods this can result in the water stress of the vegetation.

Tužinský (2007), exploring his results of a long lasting monitoring of the soil water, states that over the last 35 years, there were observed significant changes in the soil moisture dynamics and available water supply during the growing season. This was demonstrated mostly by the frequent occurrence of soil moisture cycles with a low or insufficient supply of available water and the presence of dry periods, in which was observed a significant decrease in the available water supply during a relatively short time.

The soil is significantly dried out and the available water supply decreases especially in the upper soil layers (0–20 cm). Within the whole physiological soil profile (0–100 cm), the available water amount decreases to the category low or even very low. In the case of a longer lasting drought, the vegetation is threatened by physiological weakening, premature defoliation, assimilation decrease or even termination, decrease of transpiration and growth, damage to forest stands, their vitality loss, and decrease of trees natural resistance against abiotic and biotic harmful agents.

Translated by M. Pichlerová

Acknowledgement

We acknowledge the financial support from the Project VEGA No. 1/3548/06, as well as Projects APVV–0468-06 and APVT 27-0233304.

References

Balajka, J., Lapin, M., Minďáš, J., Šťastný, p., Thalmeinerová, D. 2005. *Štvrtá národná správa o zmene klímy a správa o dosiahnutom pokroku pri plnení Kjótskeho protokolu* [The 4-th National Report of the Slovak Republic on Climate Change and the Report on Progress in implementing the Kyoto Protocol]. Bratislava: Ministerstvo životného prostredia SR, p. 17–19, 85-89.

Ištoňa, J., Čaboun, V. 2006. Hodnotenie dynamiky vlhkosti v lesných pôdach SR 1.–3. lesného vegetačného stupňa v rokoch 2004 a 2005 [Moisture dynamics of forest soils in SR evaluated in the vfvz 1–3 in years 2004–2005]. In *Bioklimatológia a voda v krajine. Bioklimatologické pracovné dni 2006 = Bioclimatology and water in the land. Medzinárodná vedecká konferencia pod záštitou dekana FMFI UK Doc. RNDr. Jána Boďu, CSc.* [International bioclimatological conference organized under the auspices of Dean of the FMFI UK Assoc. Prof. RNDr. Ján Boďa, PhD]. Nitra: Slovenská poľnohospodárska univerzita. 8 p. 1 electronic optical disc (CD-ROM).

Ištoňa, J., Čaboun, V. 2007. Reflection of climatic change in desiccation up the soils from the 2nd up to 5th altitudinal vegetation zone. In Střelcová, K., Škvarenina, J., Blaženec, M. (eds). *Bioclimatology and natural hazards. Imternational scientific conference. Proceedings.* [*17–20 september 2007, Zvolen – Poľana nad Detvou, Slovakia*]. Zvolen: Technical University, p. 83. 1 electronic optical disc (CD-ROM).

Kutílek, M. 1966. *Vodohospodářská pedologie* [Water management related soil science]. Praha: SNTL. 275 p.

Kutílek, M. 1971. Ekologická klasifikace půdní vlhkosti [Ecological classification of soil moisture content]. *Vod. Hospod.*, 9: 250–256.

Lapin, M., Damborská, I., Melo, M. 2001. Scenáre časových radov mesačných klimatických údajov pre Slovensko v období 2001–2090 [Scenarios based on time series of monthly sampled climatic variables in Slovakia in years 2001–2009]. In *Extrémy prostredia (počasia) limitujúce faktory bioklimatologických procesov. Bioklimatologické pracovné dni 2001, Račková dolina, 10.–12. septembra 2001.* Nitra: Slovenská bioklimatologická spoločnosť. [9 p.]. 1 electronic optical disc (CD-ROM).

Minďáš, J., Škvarenina, J. (eds). 2003. *Lesy Slovenska a globálne klimatické zmeny* [Slovak forests and global climate changes]. Zvolen: Technická univerzita. 128 p.

Pajtík, J., Ištoňa, J. 2003. Dynamika hrúbkového rastu duba cerového na sprašovej hline v závislosti od klimatických faktorov [Dynamics of diameter increments in Turkey oak growing on loess loam, related to climate factors]. *Lesn. Čas.*, 49: 37–47.

Soroková, M. 2001. *Režim vlhkosti pôdy pod lesnými porastmi s rozdielnym drevinovým zložením* [Dynamics of soil moisture in forest stands differing in species composition]. PhD thesis. Zvolen: Technical University in Zvolen, Faculty of Forestry. 143 p.

Tužinský, L. 1999. Bilancia vody v lesných ekosystémoch [Water balance in forest ecosystems]. *Acta Fac. for. zvolen.*, XLI, 55–65.

Tužinský, L., 2004. *Vodný režim lesných pôd* [Water regime in forest soils]. Vo Zvolene: Technická umiverzita. 101 p.

Tužinský, L., 2007. Bilancia vody v pôdach pod lesnými ekosystémami Slovenska – priestorová a časová variabilita vlhkosti pôdy [Water balance in soils in forest ecosystems in Slovakia – spatial and temporal variability in soil moisture content]. In Střelcová, K., Škvarenina, J., Blaženec, M. (eds). *Bioclimatology and natural hazards. Imternational scientific conference. Proceedings. [17–20 september 2007, Zvolen – Poľana nad Detvou, Slovakia*]. Zvolen: Technical University, 8. p. 1 electronic optical disc (CD-ROM).

Zlatník, A., 1959. *Přehled slovenských lesů podle skupin lesních typů* [Survey of Slovak forests according to the forest type groups]. Spisy Vědecké laboratoře biogeocenologie a typologie lesa Lesnické fakulty Vysoké školy zemědělské, Čís. 3. Brno: Lesnická fakulta Vysoké školy zemědělské. 92 p., 196 appendices.

Zlatník, A. 1976. Přehled skupin lesních typů geobiocenů původne lesních a křovinných v ČSSR [Survey of groups of forest types of originally forest and shrub geobiocoenes in the ČSSR]. *Zpr. Geogr. Úst. ČSAV (Brno)*, 13: 55–64.

Výskyt suchých períód v dubinách a ich vplyv na zásoby pôdnej vody

Súhrn

V práci sú uvedené hydropedologické cykly, ktoré boli zaznamenané v suchých periódach, vo vegetačných obdobiach rokov 1988 až 2006, v dubovom ekosystéme, typologicky patriacom do slt Carpineto-Quercetum. Z údajov monitoringu dynamiky vlhkosti pôdy a obsahu vody vo fyziologickom profile pôdy, ako indikátora prírodného prostredia vyplýva, že v pôdach najnižších lesných vegetačných stupňov dochádza k postupnému zvyšovaniu výskytu suchých períód, v dôsledku čoho sa mení aj objem vody v zóne aerácie a jej pripravenosť pre rastliny vo vegetačnom období. V analyzovaných suchých periódach, na ich začiatku, v obidvoch sledovaných vrstvách pôdy (0–20 cm, 0–100 cm) dominuje semiaridný interval s množstvom vody medzi hydrolimitmi bodom zníženej dostupnosti (BZD) a bodom vädnutia (BV). Na ich konci, v prevažnej miere v povrchovej vrstve pôdy, sa znižuje obsah vody do oblasti aridného intervalu, so stavom vody, s nedostatočnou až nulovou zásobou využiteľnej vody pre rastliny. Prítomnosť hydropedologických cyklov s veľmi nízkou zásobou využiteľnej vody v celom fyziologickom profile pôdy, s kapilárne ťažko pohyblivou až nepohyblivou vodou, možno odôvodniť meniacimi sa ekologickými podmienkami, osobitne zvyšovaním teploty vzduchu a deficitom zrážkových úhrnov. Reakciou rastlín na daný vlhkostný stav je zvýšená mortalita prízemnej vegetácie, zníženie asimilácie, transpirácie a prírastku, predčasný opad asimilačných orgánov a zníženie odolnosti stromov proti pôsobeniu škodlivých činiteľov.

Received November 9, 2009
Accepted February 12, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Allometry of four European beech stands growing at the contrasting localities in small-scale area

Josef Urban, Kateřina Rebrošová[1], Lumír Dobrovolný, Jiří Schneider

Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno,
Czech Republic, [1]rebruska@centrum.cz

Abstract

Urban, J., Rebrošová, K., Dobrovolný, L., Schneider, J. 2010. Allometry of four European beech stands growing at the contrasting localities in small-scale area. *Folia oecol*., 37: 103–112.

The aim of this study was to describe and compare biometrical parameters (such as breast height diameter (DBH), tree height, length of a crown, leaf area index (LAI), xylem biomass) of trees of four forest stands growing at contrasting sites in the small-scale area of 30 km^2 and to calculate and compare their allometrical models of these parameters on DBH. All forest stands were monocoenoses of European beech (*Fagus sylvatica* L.) more than 160 year old. We found statistically significant differences among the localities almost in all investigated parameters. Also proposed allometrical models were different. None of the simple allometrical models from the literature fit to all of the localities. Thus allometric models should be used only with respect to local site conditions such as soil and climatic conditions and level of competition among trees and not only with respect to certain geographic region.

Key words

allometry, *Fagus sylvatica* L., tree biometry

Introduction

European beech is one of the most common tree species in the forest across Europe. Its natural range spans from Spain to the Black sea and from the Sicily to the Southern part of Norway (Jahn, 1991). An interest in the tree biomass led to development of several allometric models (Bartelink, 1997; Ter-Mikkelian and Korzukhin, 1997; Forstreuter, 1999; Santa Regina and Tarrazona, 2001; Zianis and Mencuccini, 2003; Cienciala et al., 2005). Most of them use as scaling parameter only tree diameter at breast height (DBH) using equation of the type $y = a + DBH^b$. Some models apart from the DBH include also tree height using three parameter model $y = a + DBH^b + h^c$ (Zianis and Mencuccini, 2003; Cienciala et al., 2005). Each of these models was developed by analysis of trees of a different range of DBH in one particular geographic region which is one of the reasons for the difference in results obtained by different models running over similar data. However the tree biomass vary considerably not only with species, its size and geographic location but also with stand age, site quality, climate and stocking density of stands (Cannell, 1982; Bartelink, 1997). Therefore the most sophisticated models (usually growth models) take into account not only tree height but also other parameters e.g. tree position within the canopy, the site and climatic conditions etc. (Fabrika and Ďurský, 2005).

In theory, the allometric equations describing tree shape are affected by the physiological requirements of the tree. The most important are water transport, light interception and mechanical support of trees against the gravity or wind (Niklas, 1994). From the hydraulical point of view tree may be seen as a network of interconnected pipes (Zimmerman, 1983). By the "pipe rule theory" (Shizonaki et al., 1964) the amount of roots should be sustained by the unit of sapwood area of a tree and by the unit of evaporating leaves. West et al. (1999) integrated both biomechanical and hydraulical parameters of the tree and developed a model which predicts several plant variables (tree height and DBH, number of leaves, etc.) in relation to plant biomass.

The aim of this study is to compare the stand structure of the mature European beech forest stands growing on contrasting localities in a small-scale area of Buchlovske vrchy hills, East Bohemia. The obtained equations are compared with the allometric equations for the beech found in the literature.

Material and methods

Studied sites are located in the east of the Czech Republic, at the outer margin of western Carpathian geographic region, in area of Chriby ridges (Rauser, 1971). The mean annual temperature at these plots was 7.0 °C, the mean annual precipitation 744 mm.

In this region we chose four plots of the size of 100 × 100 m at sites "Rynek, Holy kopec, Machova dolina and Ocasek". The studied plots were located at different soil and phytocoenosis types (Table 1). The soil types were different types of cambisols from nutrient poor (oligotrophic) to rich (mesotrophic) with different proportion of skeleton, sometimes with marks of a gley process. Types of phytoceonosis in different plots was indicating nutrient poor (Machova dolina plot), medium (Holy kopec) and nutrient rich (Rynek, Ocasek) site. Currently all plots are covered with monocoenosis of mature European beech forest stands. All forest stands are from the 1990 excluded from forest management being a part of natural reserve.

In all four localities were set the research plots 100 × 100 m where the measurements were taken. Aboveground structure of forest stand we measured by FieldMap (IFER, Jílové u Prahy); the number and position of trees (with declared accuracy of 3 cm), their breast height diameter (DBH, accuracy 1 cm), height of trees and their crown base (with resolution 0.25 m), and crown projection area (A_{pro}) was measured in all trees with DBH larger than 10 cm. Additionally we measured position of snags together with the level of decomposition. Data were exported in form of maps as the dBase format. Parameters of trees were exported in a form of MS Access file. When considering the equipment we used a laser distance meter Impulse 200LR with resolution 1 cm, electronic compass MapStar Module II, Hammerhead laptop and ranging poles with reflecting glass. GPS coordinates were measured with Trimble Pro XH device. Tree diameters were measured by caliper with resolution of 1 cm from perpendicular sides of the tree. Heights were measured by the height meter Vertex IV with resolution 0.25 m. Leaf area index (LAI) was measured by "pitching method" on whole-stand level. After leaf-fall the samples of litter were collected with the pointed stick from the randomly chosen places in the forest. The number of leaves collected during one pitch expressed the LAI of the stand. Four hundred samples were taken from each stand.

To estimate individual tree biomass we used SIBYLA model (Fabrika and Ďurský, 2005). SIBYLA is a growth model representing East-Czech and Slovakian growth conditions and management environment. The model requires input of individual tree data (DBH, height, coordinates, crown parameters and tree quality – in means of its social position in the forest and health condition). The second part of input requires data about site conditions (climate, type of soil). Input data was generated from forest inventory made by FieldMap as described above. As an output a table was generated with each individual tree characterized by the dry weight of stem-wood, dry weight of roots and stump-wood, dry weight of branches, dry weight of bark and dry weight

Table 1. Description of the four investigated localities

Description/Locality	Rynek	Holy kopec	Machova dolina	Ocasek
Number of stand in forest management plan	204A17	203E17	402E17	57B17/1
Age [years]	167	165	190	186
Forest type (Plíva, 1991)	3B9 Sloping Querceto-Fagetum mesotrophicum	4D9 Sloping Querceto-Fagetum acidophilum	3K6 Musci Querceto-Fagetum acidophilum	3A2 Tilii-Querceto-Fagetum acerosum lapidosum with Melica uniflora
Soil type (Nemecek, 2001)	Cambisol mezotrophic	Gleyly cambisol mesotrophic	Cambisol oligotrophic	Rankered cambisol
Type of biotope (Natura 2000)	9130 Asperulo fagetum	9130 Asperulo fagetum	9110 Luzulo-fagetum	9130 Asperulo fagetum
Type of phytocoenosis – association (Moravec, 2000)	Melico-Fagetum	Carici-pilosae-Fagetum	Luzulo-Fagetum	Dentario-eneaphylli-Fagetum
Type of geobiocen	3BC3	4B(BC)3	3A2-3	3BC3
(Bucek and Lacina, 2002)	Querci-Fageta aceris	Fageta typica	Fageta quercina	Querci-Fageta aceris
Relative order in fertility	1.	2.	3.	1.
Altitude [m]	490	480	430	550
Longitude [°N]	49.10	49.11	49.16	49.10
Latitude [°E]	17.28	17.29	17.31	17.24

Table 2. Allometric equations from the literature used to calculate aboveground biomass of the trees. Abbreviations: DBH, stem diameter in the breast height; h, height of the tree

		Parameters		
Author, site	Equation	a	b	c
Ter-Mikkelian, 1997, Maine	$y = a.DBH^b$	0.2013	2.2988	
Ter-Mikkelian, 1997, New Hampshire	$y = a.DBH^b$	0.1957	2.2538	
Bartelink, 1997	$y = a.DBH^b$	0.0798	2.601	
Santa, 2001	$y = a.DBH^b$	0.1326	2.4323	
Zianis, 2003	$y = a.DBH^b$	0.2511	2.3485	
Forstreuter, 1999	$y =a.DBH^b$	0.1293	2.44	
Cienciala, 2005	$y = a.DBH^b$	0.453	2.139	
Cienciala, 2005	$y = a.DBH^b+h^c$	0.047	2.121	0.697
Bartelink, 1997	$y = a.DBH^b+h^c$	0.0306	2.347	0.59

of leaves. All output data are in kg units with resolution of two digits.

Tree biomass was additionally estimated using nine other allometric models (Table 2). Seven of them were based only on relation to DBH (Bartelink, 1997; Ter-Mikkelian and Korzukhin, 1997 (two models for Maine and New Hampshire); Forstreuter, 1999; Santa Regina and Tarrazona, 2001; Zianis and Mencuccini, 2003; Cienciala et al., 2005), remaining two (Barte-link, 1997; Cienciala et al., 2005) used DBH together with height of the tree to calculation. One-way analysis of variance (anova, $\alpha = 0.05$) was used to find diffe-rences among the models.

Statistical analysis was performed using software Statistica 8.0 (StatSoft, Inc.). To test the hypothesis and scale-up parameters to the stand level linear and non-linear regression analysis, analysis of variance (anova) and general linear model analysis was used. To estimate allometric relationships one-dimensional regression analysis was used. From the linear and several non-linear regression models the one with the highest r^2 was chosen. The significance of the r^2 and of the model was tested by anova ($\alpha = 0.05$ and one degree of freedom). In case the calculated F value was higher than the threshold for $F_{0.05,\ n\text{-}2,1}$ we considered the proposed model as significant. In linear models we also tested the significance of the absolute coefficient by a t-test for $t_{0.025,\ n\text{-}2}$; if the calculated value was lower than the threshold value the coefficient was excluded from the equation. To test the difference between individual parameters of selected plots one-way anova was used. The α value was set to 0.05 and P value to 95%. In case the parameter was dependent on tree DBH and comparing of similar-sized trees was required, general linear model analysis was used instead of anova.

Results and discussion

The highest number of trees was growing at the site Machova dolina and the lowest at Rynek and Ocasek site, 292 and 123 (124) pcs ha^{-1} respectively. The number of trees at localities under investigation was inversely correlated with mean DBH of trees. The thickest trees were at the localities Rynek and Ocasek, having mean DBH of 61 and 64 cm, with thickest trees of DBH 117 and 100 cm respectively. Despite the equal number of trees at these two localities the DBH distribution in diameter classes was different with more trees of lower DBH (understorey trees) at Rynek. The lowest mean DBH of 37 cm was observed at locality Machova dolina (Table 3). The variation coefficient was similar in all localities; the lowest variability in DBH distribution was found at locality Holy kopec (Table 3). The highest value of stem basal area in breast height (BA) per hectare was measured at Holy kopec (48 m^2), the lowest value of 34 m^2 despite the highest number of trees, at Machova dolina (Table 4, Fig. 1).

The tallest trees were found at Holy kopec site having in average as much as 38 m in height. Trees at Rynek and Ocasek were only a bit smaller (however there was statistically significant difference) having mean height 36 and 34 m respectively. Trees from the Machova dolina site with mean height of 16.5 m was reaching less than half of the height of trees from another sites. At this site was also found the highest variability in the height distribution. In contrary the lowest variability was observed at Holy kopec. Trees there were rather uniform in their height what is described by low index of variation (7%) (Table 3). The height of trees over diameter classes may be described by allometrical equation in the shape of the logarithmic function. Equations and corresponding coefficients of determination (r^2 between 0.33 and 0.42) are in Table 5 and Fig. 2a. The heights of the trees in the four studied sites were also modeled using equations of Levakovič, Michajlov and Näslund based on measured DBH and corresponding height of a certain tree (Michajlov, 1952; Korf, 1972). The heights calculated using these three models did not significantly differ from the heights calculated by logarithmic function.

Our proposed models were compared with the logarithmic model of Guericke (2001) and with another

Table 3. Basic statistical characteristics of biometrical characteristics of trees at four studied localities

	Site	Number of trees	Mean value	Standard deviation	Maximal value	Minimal value	Index of variability [%]
DBH [cm]	Rynek	123	61.0	16.0	117.0	29.0	26
	Holy kopec	233	50.0	11.0	80.0	26.0	**22**
	Machova dolina	292	37.0	10.0	73.0	10.0	27
	Ocasek	124	64.0	16.0	100.0	29.0	25
Height [m]	Rynek	123	36.2	3.8	45.0	21.0	10
	Holy kopec	233	38.1	2.6	43.0	25.0	**7**
	Machova dolina	292	16.5	4.6	31.5	2.5	28
	Ocasek	124	34.5	3.1	40.0	25.0	9
Crown length [m]	Rynek	123	18.0	6.1	31.0	4.0	34
	Holy kopec	233	17.0	4.5	30.0	4.0	**26**
	Machova dolina	292	11.0	3.12	20.0	3.0	29
	Ocasek	124	17.0	4.7	21.0	6.0	28
Crown projection area [m^2]	Rynek	123	82.0	71.0	409.0	3.0	87
	Holy kopec	233	34.0	24.0	142.0	1.2	71
	Machova dolina	292	42.0	21.0	116.0	6.0	**50**
	Ocasek	124	49.0	37.0	171.0	0.5	76

Table 4. Leaf area index (LAI), cumulative values of basal areas (BA), crown ground projection areas (A_{PRO}) per hectare of forest stand and their ratios

Site	BA [m^2]	A_{PRO} [m^2]	LAI	A_{PRO}/BA ratio	LAI/A_{PRO} ratio
Rynek	38.9	10,146	3.9	261	3.8
Holy kopec	48.2	7,839	4.2	163	5.4
Machova dolina	33.8	12,359	3.6	366	2.9
Ocasek	41.9	6,050	3.8	144	6.2

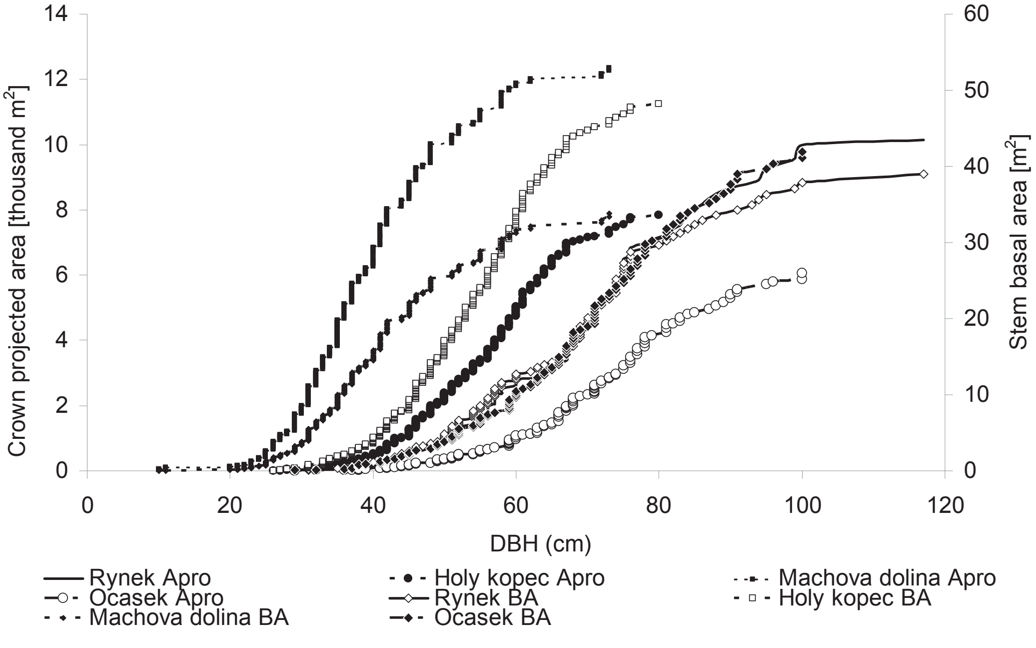


Fig. 1. Cumulative distribution of the crown projected area (A_{PRO}, single line) and stem basal area in the breast height (BA, double line) over the diameter classes in four studied localities

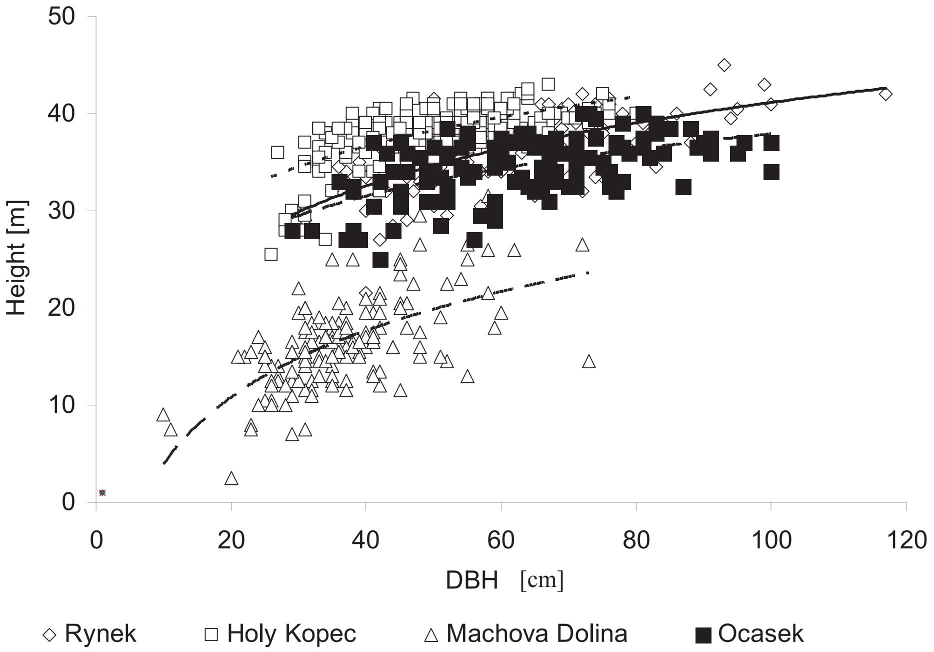


Fig. 2a. Dependence of tree height on the DBH (breast height diameter) at the four studied localities. Allometric equations with corresponding correlation coefficients are written in the Table 5. Smallest trees are at nutrient poor site Machova dolina, tallest at the Holy kopec.

Table 5. Allometrical equations for calculation of the tree height (H). Seven equations have been taken from the literature, last four equations are the proposed logarithmical models derived from the parameters of the trees at our sites. Abbreviation DBH is stem diameter in the breast height.

Author/Site	Model	R²
Guericke, 2001	$H = 11.447.\ln(DBH) - 11.885$	
Kinderman, 1998	$H = 1.3 - \frac{DBH^2}{2.07 + 0,507 + 0.0215.DBH^2}$	
Bartelink,1997	$H = 1.732 + DBH^{0.769}$	
Forstreuter,1999	$H = 3.24083DBH^{0.613065}$	
Widlowski, 2003	$H = 1.3 + \left(\frac{DBH}{1.31811 + 0.151515.DBH}\right)^2$	
Levakovič	$H = 1.3 + a\left(\frac{DBH}{1 + DBH}\right)^b$	
Michajlov	$H = 1.3 + ae^{\frac{b}{DBH}}$	
Näslund	$H = 1.3 + \frac{DBH^2}{a + b.DBH^2}$	
Rynek	$H = 9.35.\ln(DBH) - 1.92$	0.42
Holy kopec	$H = 7.34.\ln(DBH) + 9.53$	0.40
Machova dolina	$H = 9.87.\ln(DBH) - 18.76$	0.39
Ocasek	$H = 6.99.\ln(DBH) - 5.69$	0.33

exponential models (Bartelink, 1997; Kinderman, 1998; Forstreuter, 1999; Widlowski, 2003). None of the models from the literature fit to all localities. The lowest values of height were obtained by Bartelink (1997) model. This model fits to the data from Machova dolina plot (Fig. 2b). Thus Bartelink (1997) model is suitable for the small trees of less than 30 cm in DBH growing at nutrient poor site. Models of Kinderman

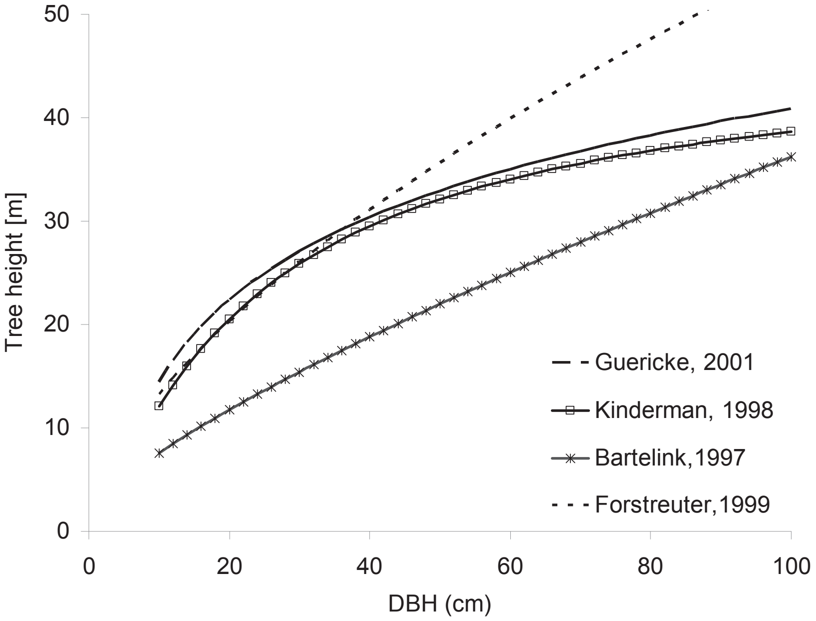


Fig. 2b. Allometric relationship of the tree height on breast height diameter (DBH) estimated by different models.Model of Bartelink, 1997 fit to the data from the nutrient poor site Machova dolina. Remaining models fit to the sites Rynek and Ocasek. None of the models from the literature fit to the tall and thin trees from the Holy kopec.

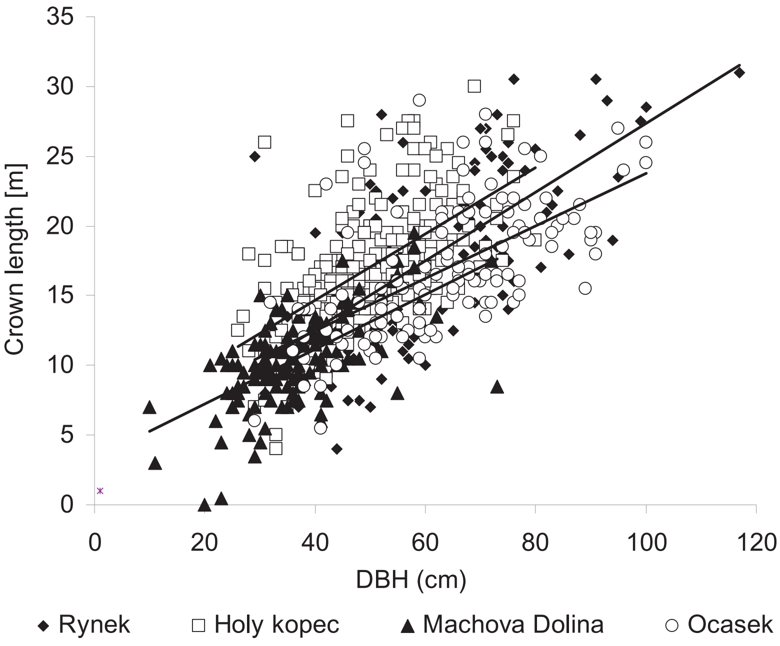


Fig. 3. Dependence of the length of the crown on the DBH. Allometrical equations and corresponding r^2: Holy kopec: $y = 0.24DBH + 5.17$, $r^2 = 0.34$, Rynek: $y = 0.25DBH + 2.73$, $r^2 = 0.43$, Machova dolina: $y = 0.20DBH + 3.29$, $r^2 = 0.40$, Ocasek: $y = 0.19\ DBH + 4.95$, $r^2 = 0.39$. Abbreviation: DBH, breast height diameter

(1998), Guericke (2001) and Widlowski (2003) fit to trees at the Ocasek site. Guericke's model fit also to data from locality Rynek; it is the only model that fit to data from two localities. None of the models from the literature fit to the Holy kopec locality with thin and tall trees. Model by Forstreuter (1999) is useful for studying smaller trees (DBH less than 40 cm) and overestimates the height of the large ones, so did not fit to any of localities.

The mean length of the crown reaching 17 to 18 m was similar in almost all localities with exception of Machova dolina where the mean crown length was only 11.5 m. Length of the crown was linearly dependent on the size of a tree ($r^2 = 0.34–0.43$, Fig. 3). We found a significant difference in height of crown base between the localities however no correlation with tree diameter (r^2 less than 0.10), which is in contrary with some other authors that provide allometric equations, though rather for lower DBH (Bartelink, 1997; Guericke, 2001).

Crown ground projected area (A_{PRO}) was positively correlated with tree DBH (Table 6). The highest mean A_{PRO} was measured in trees at the site Rynek, reaching as much as 82 m^2. At this locality was also the highest scatter in the crown size, because of presence of the extremely large trees. The smallest ground projection areas were at the site Machova dolina. However these differences in absolute values were evoked by different size of the trees in different localities. Trees at Machova dolina in spite of being smallest had the biggest A_{PRO} /basal area ratio and thick trees at Holy kopec and Ocasek had

Table 6. Allometrical equations for the calculation of the crown ground projected area (CA). Three equations are from the literature, last four equations are our proposed models for the different sites.

Author/site	Model	R^2
Guericke, 2001	$CA = \pi \,.\, (0.0821DBH + 0.76694)^2$	
Nagel et al., 2002	$CA = \pi\left((1.04185 + 0.075DBH).\left(1 - \exp^{-\left(\frac{DBH^{1.3341}}{5.7292}\right)}\right)\right)^2$	
Bartelink, 1997	$CA = \left(\frac{8.560 + 0.0286.DBH^{2.623}}{}\right)^{0.98232}$	
Rynek	$CA = 3.99 \,.\, e^{0.04DBH}$	0.65
Holy kopec	$CA = 1.35 \,.\, e^{0.06DBH}$	0.64
Machova dolina	$CA = 1.41DBH - 9.87$	0.51
Ocasek	$CA = 7.10^{-5} \,.\, DBH^{3.18}$	0.67

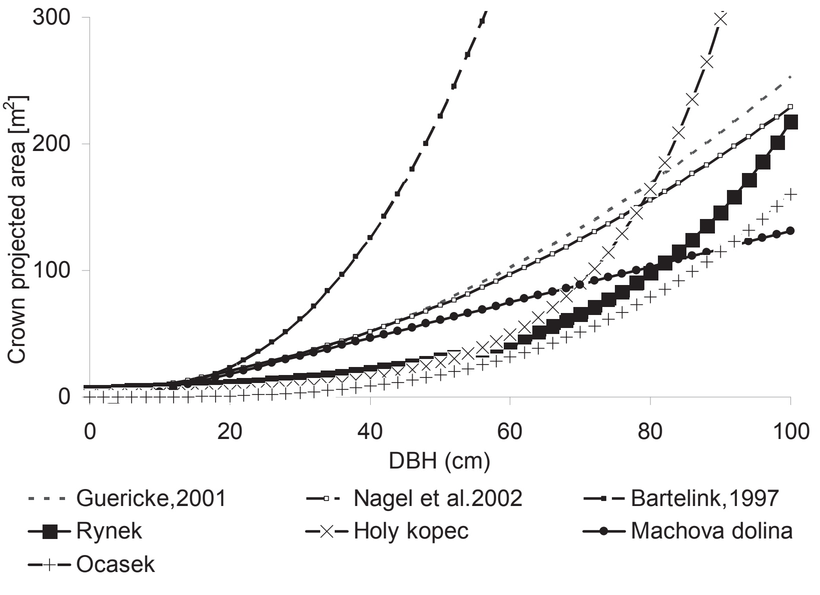


Fig. 4. Dependence of the crown ground projection area (A_{PRO}) on the DBH. Allometric equations with corresponding correlation coefficients are written in the Table 6. Exponential models from the literature were calibrated on smaller trees and therefore overestimates A_{PRO}.

relatively small crowns (Fig. 4, Table 4). In the locality Machova dolina without extremely huge crowns the best fitting equation had the linear shape whereas in the remaining localities was its shape exponential. The highest cumulative value of crown projected areas was measured at Machova dolina reaching 12,300 m^2, the lowest of 6,100 m^2 at Ocasek (Table 4, Fig. 1).

Leaf area index (LAI) was highest at Holy kopec (4.2); somewhat lower LAI was measured at Rynek (3.9) and Ocasek site (3.8). The lowest LAI was at Machova dolina (3.6). Density of crowns was estimated as a ratio between LAI and sum of A_{PRO}. Densest crowns were at Holy kopec and Ocasek, sparse at Machova dolina (Table 4). The sum of A_{PRO} at Rynek and Machova dolina is higher than actual size of the plot which suggests mutual shading of the trees. Crowns are relatively wide but with low density of leaves. The remaining two localities are much less covered with tree crown (which are, in contrary, denser, Table 4); thus light can be intercepted not only by the top of the crown but also by its sides. Than the amount of sun leaves (Čermák, 1989) which are most important for tree transpiration and photosynthesis may be higher.

Proposed allometric models between DBH and A_{PRO} were compared to exponential models found in the literature. The model of Bartelink (1997) was calibrated to relatively small trees (DBH less than 30 cm) and was not suitable to our purposes (Fig. 4). Models of Guericke (2001) and Nagel et al. (2002) were fitting to the trees from Machova dolina however at remaining localities overestimated A_{PRO} in trees of lower dimensions (DBH less than 60 cm). Our proposed models fit to the trees in particular localities but can be used (as well as any exponential model) only within a given range of DBH. Effort to use exponential models in trees thicker than calibration limit leads to the overestimation of results.

Tree aboveground biomass estimated by SIBYLA model was between 199 and 587 $m^3\ ha^{-1}$ for Machova dolina and Holy kopec respectively (Table 7). Total tree biomass in all stands together estimated by different models ranged between 1,408 Mg for model calibrated to Maine (Ter-Mikkelian and Korzukhin, 1997) and 2,943 Mg estimated by model calculating with both DBH and tree height (Bartelink, 1997).

Overall the biomass estimates running the models using DBH as a single predicting parameter was significantly lower than estimation of models based on both DBH and tree height (with the exception of the SIBYLA model). The values obtained by model for Maine (Ter-Mikkelian and Korzukhin, 1997) were the lowest in all sites. The results of the models based on DBH (Santa Regina and Tarazona, 2001; Forstreuter, 1999 and Cienciala et al., 2005) were similar. The values calculated by models using both DBH and tree height (Bartelink, 1997; Cienciala et al. 2005) were the highest (Table 7).

Forest stands of a same species composition growing even in small-scale area may have different structure due to local differences in site conditions and different competition pressure (different stand density) during their development. Therefore allometric equations should be used with this precaution. Their selection should depend not only on the geographic region but also, if possible, on the knowledge of site conditions, age and level of competition between trees. Growth and development of the trees was mostly influenced by the site fertility (e.g. soil, climatic conditions, and slope exposition). The differences among the localities with comparable site conditions were smaller, however still statistically significant.

Acknowledgement

Authors wish to thanks to prof. Jan Čermák and to ass. prof. Jan Štykar from Mendel University in Brno for their valuable help with this paper. This research was financially supported by internal grant agency of Faculty of Forestry and Wood Technology at Mendel University

Table 7. Results of the calculations of the tree biomass for our stands using different models ($t\ ha^{-1}$). Three different types of models were used. Calculations of the seven models were based only on tree diameter in the breast height (DBH), three of the models were based on using both DBH and tree height (h). The growth model Sybila was based on nine parameters including e.g. DBH, height, competition between trees, site fertility. Note the high biomass estimates of the models calculating with the tree height. For the references to the models see the text.

Equation type	$y = a\ DBH^b$							$y = a\ DBH^b + h^c$		
Author/Site	Maine	Santa	Forstreuter	Cienciala	Bartelink	New Hampshire	Zianis	Cienciala	Bartelink	SYBILA
Rynek	353	410	413	404	505	509	544	749	811	472
Holy kopec	407	458	460	484	541	574	620	761	799	587
Machova dolina	264	287	288	327	326	364	397	435	445	199
Ocasek	383	445	449	437	550	553	590	819	888	488
Total aboveground biomass	1,408	1,600	1,610	1,653	1,922	1,999	2,151	2,765	2,943	1,746

in Brno, projects "Utilization of synthesis of ecosystem characteristics of forest stands in landscape protection" and "Seasonal dynamics of absorbing root surfaces measured by the method of electrical impedance".

References

Bartelink, H. H. 1997. Allometric relationship for biomass and leaf area of beech (Fagus sylvatica, L.). *Ann. Forest Sci.*, 54: 39–50.

Buček, A., Lacina, J. 2002. *Geobiocenologie II.* [Geobiocenology II.] Brno: MZLU v Brně. 240 p.

Cannell, M.G.R. 1982. *World forest biomass and primary production data.* London: Academic Press. 391 p.

Chytrý, M., Kučera, T., Kočí, M. 2001. *Katalog biotopů České Republiky* [Catalog of biotopes of Czech Republic]. Praha: Agentura ochrany přírody a krajiny.

Čermák, J. 1989. Solar equivalent leaf area as the efficient biometrical parameter of individual leaves, trees and stands. *Tree Physiol.*, 5: 269–289.

Cienciala, E., Cerny, M., Apltauer, J., Exnerova, Z. 2005. Biomass functions applicable to European beech. *J.Forest Sci.*, 51: 147–154.

Fabrika M., Ďurský, J. 2005. Algorithms and software solution of thinning models for SIBYLA growth simulator. *J.Forest Sci.*, 51: 431–445.

Forstreuter, M. 1999. *Ergebnisbericht: Ökologie der Gehölze* [Report: Woodland Ecology]. Report SS99. Berlin: Technische Universität, Institut für Ökologie und Biologie. 22 p.

Guericke, M. 2001. *Growth dynamics of mixed stands of beech and European larch*. Technical report, Fakultät für Forstwissenschaften und Waldökologie. Göttingen: Georg-August Universität.

Jahn, G. 1991. *Temperate deciduous forests of Europe.* In Rohrig, E., Ulrich, B. eds. Ecosystems of the world 7. Temperate deciduous forests. London: Elsevier, p. 377–502.

Kindermann, G. E. 1998. *Die Flächenanteile der Baumarten.* Diplomarbeit. [The tree species area. Diploma work.] Perchtolsdorf, Deutschland: Universität für Bodenkultur, Institut für Waldwachstumsforschung.

Korf, V. 1972. Dendrometrie [Dendrometry]. Praha: SZN. 371 p.

Michajlov, I.L. 1952. *Dendrometriya* [Dendrometry]. Skoplje.

Moravec, J. 2000. *Přehled vegetace České republiky* [Vegetation survey of the Czech Republic] Praha: Academia.

Nagel, J., Albert, M., Schmidt, M. 2002. Das waldbauliche Prognose- und Entscheidungsmodell BWINPro6.1 [The forecasting and silvicultural decision model BWINPro6.1.] *Forst und Holz*, 57: 486–493.

Nemecek, J. 2001. *Taxonomický klasifikační systém půd České republiky* [Taxonomical classification system of soils in the Czech Republic]. Praha: ČZU Praha, VÚMOP Praha.

Niklas, K. J. 1994. *Plant allometry. The scaling of form and process.* Chicago: The University of Chicago Press. 395 p.

Plíva, J. 1991. *Funkčně integrované lesní hospodářství I. Přírodní podmínky v lesním plánování*. Brandýs nad Labem: ÚHÚL.

Santa Regina I., Tarazona T. 2001. Organic matter and nitrogen dynamics in a mature forest of common beech in the Sierra de la Demanda, Spain. *Ann. Forest Sci.*, 58: 301-314.

Shizonaki, K.K., Yoda, K., Hozumi, L., Kira, T. 1964. A quantitative analysis of plant form – the pipe model theory. I. Basic analysis. *Jap. J. Ecol.,* 14: 97–105.

Ter-Mikkelian M.T., Korzukhin, M.D. 1997. Biomass equations for sixty-five North American tree species. *Forest Ecol. Mgmt*, 97: 1–24.

West G. B., Brown, J. H., Enquist B. J. 1999. A general model for the structure and allometry of plant vascular system. *Nature*, 400: 664–667.

Widlowski, J.L., Verstraete, M., Pinty, B., Gobron, N. 2003. *Allometric relationships of selected European tree species: parametrizations of tree architecture for purpose of 3-D canopy reflectance models used in the interpretation of remote sensing data: Betula pubescens, Fagus sylvatica, Larix deciduas, Picea abies, Pinus sylvestris.* Luxembourg : Office for Official Publications of the European Communities, 2003. 61 p.

Zianis, D., Mencuccini, M. 2003. Aboveground biomass relationship for beech (Fagus moesiaca Cz.) trees in Vermio Mountain, Northern Greece, and generalized equations for Fagus sp. *Ann. Forest Sci.*, 60: 439–448.

Zimmerman, M. H. 1983. *Xylem structure and the ascent of sap.* Berlin: Springer. 139 p.

Alometria štyroch európskych bukových porastov rastúcich na kontrastných lokalitách v maloplošných územiach

Souhrn

Cieľom tejto štúdie bolo opísať a porovnať biometrické parametre (napríklad priemernej hrúbky v $d_{1,3}$ (DBH), výšky stromov, dĺžky koruny, index listovej plochy (LAI), xylémovej biomasy) stromov štyroch lesných porastov pestovaných v rozdielnych lokalitách v maloplošnom merítku na ploche 30 km^2, vypočítať a porovnať ich alometrické modely. Študované lokality sa nachádzajú vo východnej časti Českej republiky, na vonkajšom okraji geografickej oblasti západných Karpát, v oblasti Chřibů (Rauser, 1971). Všetky lesné porasty pochádzajú z monokultur buka lesného (*Fagus sylvatica* L.) viac ako 160 rokov starých. Zistili sa štatisticky významné rozdiely medzi lokalitami takmer vo všetkých sledovaných parametroch. Výsledky porovnávaných modelov boli odlišné. Žiaden z analyzovaných jednoduchých alometrických modelov nebol vhodný pre všetky lokality. Alometrické modely by mali byť použité so zreteľom na miestne podmienky, ako sú pôdne a klimatické podmienky a úroveň sociálneho postavenia stromu (jedinca) v poraste, ale aj s ohľadom na určité geografické oblasti.

Najhrubšie stromy boli na lokalitách Rynek a Ocásek, ktoré mali priemer 61 a 64 cm, resp. 100 a 117 cm. Variačný koeficient bol podobný vo všetkých lokalitách, najnižšia variabilita v distribúcii DBH bola na lokalite Holý kopec (tabuľka 3). Najvyššia hodnota kruhovej základne porastu (BA) na hektár bola nameraná v lokalite Holý kopec (48 m^2), najnižšia hodnota 34 m^2 napriek najväčšiemu počtu stromov v lokalite Máchova dolina (tabuľka 4, obrázok 1).

Index listovej pokryvnosti (LAI) bol najvyšší v lokalite Holý kopec (4,2), o niečo nižší LAI bol nameraný na lokalite Rynek (3,9) a Ocásek (3,8). Najnižšie LAI bol na ploche Máchova dolina (3,6). Hustota korún sa odhaduje ako pomer medzi LAI a celkovou výškou A_{PRO}.

Najviac rozdielne sú biometrické parametre na lokalite Máchova dolina. Tu sa vyskytuje najviac stromov na plochu. Najviac podobné sú lokality Rynek a Ocásek.

Received January 5, 2010
Accepted May 11, 2010

FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Phenotypic variation in chestnut (*Castanea sativa* Mill.) natural populations in Hyrcanian forest (north of Iran), revealed by leaf morphometrics

Mehrdad Zarafshar[1], Moslem Akbarinia[*2], Piero Bruschi[3], Sieid Mohsen Hosseiny[4], Hamed Yousefzadeh[5], Mehdi Taieby[6], Ali Sattarian[7]

[1, 2, 4, 5]Department of Forestry, Natural Resource Faculty, Tarbiat Modaress University, Noor, Mazandaran, Iran
[3]Laboratory of Applied and Forest Botany, Department of Plant Biology, University of Florence, Italy
[6]Department of Forestry, Gorgan University, Gorgan, Golestan, Iran
[7]Department of Forestry, Gonbad Kavoos University, Gonbad Kavoos, Iran

Abstract

Zarafshar, M., Akbarinia, M., Bruschi, P., Hosseiny, S.M., Yousefzadeh, H., Taieby, M., Sattarian, A. 2010. Phenotypic variation in chestnut (*Castanea sativa* Mill.) natural populations in Hyrcanian forest (north of Iran), revealed by leaf morphometrics. *Folia oecol*., 37: 113–121.

Sweet chestnut (*Castanea sativa* Mill.) is marginally distributed – as a rare species, in Hyrcanian forest, located in the north of Iran. In Iran, this species is economically important for timber and nut production, therefore its conservation is very necessary. However, no information exists on its variability in the Iranian chestnut populations. The aim of this study is to survey the variability in leaf morphology of three chestnut natural populations. Twenty trees per a population and forty leaves per a tree were sampled, data of nine characteristics (lamina length, lamina width, petiole length, distance from leaf base to the leaf maximum width, tooth width, tooth length, tooth distance, vein (count variable), teeth (counted variable) and four characteristic ratios (leaf length/leaf width, leaf length/petiole length, leaf length/distance from leaf base to the widest point, distance from leaf base to the leaf widest point/petiole length), were recorded. Principal components analysis (PCA) was used to separate inter-relationships into statistically independent basic components. Most of the variation (85%) was explained by the first four components, and leaf size emerged as the most important variable in the corresponding eigenvectors. We used one-way ANOVA on the scores of the factors extracted in the PCA. These analyses revealed significant between-population differences with regard to most of factors. The results of discriminant analysis showed a high percentage of correctly classified cases in all actual populations (in total 93%). The patterns of leaf plasticity exhibited low values for all parameters. We concluded that leaf parameters are suitable variables for detecting levels of phenotypic variability among chestnut natural populations. The high diversity observed in the populations is very important for the conservation of the species genetic resources.

Key words

Chestnut, Iran, morphological traits, plasticity, variation

Introduction

The genus *Castanea* (Fagaceae) consists of seven species widely distributed across temperate zones of the Northern Hemisphere (Rutter et al., 1990). Among these species, European or sweet chestnut (*Castanea sativa* Mill.) is indigenous to the Caucasus Mountains (Ertan, 2007) and distributed in Southern Europe and

---

* Corresponding author address: Tarbiat Modaress University, Noor, Mazandaran, Iran, Box 14155-4838;
Tel.: +98-122-6253103, +98-122-6253101; Fax: +98-122-6253499; E-mail: Akbarim@modares.ac.ir

throughout the Mediterranean regions (Aravaopoulos et al., 2001).

Castanea sativa has been long recognized as a multi-purpose species (Aravanopoulos, 2005), because it is widely cultivated for timber and nut production, and because it represents an integral part of economy in many areas, particularly in rural regions (Diamandis and Perlerou, 1996).

In Iran, this species, marginally distributed in Western Hyrcanian forest (in the north of Iran – Gilan province), was first studied by Jazireie (1961). Although *Castanea sativa* has been called a rare species in Iran, and the natural stands of this species are protected stands, the number of trees per hectare is decreasing continuously. Seed collection by indigenous people, grazing and diseases are the main factors affecting chestnut distribution in Iran. Rampant seed scavenging by humans has nearly eliminated the ability of chestnut stands to regenerate naturally.

Because excessive utilization is one of the main destroying factors in *Castanea sativa* natural populations, sound management of natural stands is necessary (Aravanopoulos et al., 2001). Evaluation of genetic diversity and population structure of natural Chestnut stands is crucial for good management strategies and conservation strategy and sustainable utilization of this natural resource (Lang and Hang, 1999). When selecting gene conservation strategies, the magnitude and structure of genetic variation in natural populations must be known.

Morphological traits, especially ”easy to use” and unambiguous traits (Cousen, 1963; Olsson, 1975; Kremer et al., 2002), have often served as tools for studying genetic diversity (Neophytou et al., 2007) because they sometimes differentiate faster than isoenzymes or selective neutral DNA markers (Ishida et al., 2003). Generally, population relationships and diversity via the study of morphological traits form an important component in the study of species (Aravanopoulos, 2005).

Traditionally, leaf morphological traits have been employed by scientists for studying phenotypic diversity. This has been widely accepted, because leaves are the most important organs for photosynthesis and transpiration in plants, and arrangement, size, shape and anatomy of leaves differ greatly in different environments (Bruschi et al., 2003), and are easy to measure (Neophytou et al., 2007).

To our knowledge, no such study has been pursued on *Castanea sativa* natural populations in Hyrcanian forest. Porbabaei (2008) has surveyed ecological aspects in the Iranian Chestnut natural stands only. The use of multivariate statistics, as an addition to the classical univariate approach, provides an opportunity to reveal the importance of the morphometric traits in phenotypic diversity studies (Aravanopoulos, 2005). In our study, we analyzed leaf morphological traits by means of multivariate analysis, in order to evaluate phenotypic variation and likely kin groups in a natural stand of chestnut.

Material and methods

Three main natural populations of *Castanea sativa* in Hyrcanian forest (in the north of Iran – Gilan pro-vince) including Siamazgi valley, Vissrod valley and Ghalerodkhan valley were sampled (Fig. 1, Table 1). We first selected 20 mature trees per ech population. In order to minimize the possibility of intraspecific crossing, the trees were chosen to be at least 50 m apart. Forty leaves were collected from each of 20 trees per population. The leaves were sampled from the four sides of tree (10 leaves from each side) at 2.0 meters above the ground. The selected leaves did not show signs of abnormal growth, mechanical damage, pathogen presence or insect infestation. The parameters measured included nine morphological characters: lamina length (LL), lamina width (LW), petiole length (PL), distance from leaf base to the leaf maximum width (BW), leaf tooth width (LTW), leaf tooth length (LTL), tooth distance (TD), vein (count variable), teeth (count variable – Fig. 2) and four characters ratios: leaf length/ leaf width (LL/LW), leaf length/ petiole length (LL/LP), leaf length/distance from leaf base to the widest point (LL/BW), distance from leaf base to the leaf widest point/petiole length (BW/PL). These ratios, which form independent shape variables, have been used extensively in leaf morphometrics (Dickinson et al., 1987).

To correct for allometric effects, we calculated a measure of leaf overall size as the root square of the product (total leaf length × blade width) (Blue and Jensen, 1988). This new variable was regressed against leaf parameters, and the residuals used as input in the successive analyses. Thus, for each character *i* and OTU *j* (Operational Taxonomic Units) size-adjusted variables *Yij* were determined according to the formula: *Yij* adj. = *Yij* – *Yij*-cap, where *Yij*-cap was the expected value of *Yij* given the size of OTU *j*. Descriptive statistics were computed for three populations tested. Assumptions of normality were checked with Shapiro-Wilk's test. Normality of distribution of the characters was assessed for all variables. Principal components analysis (PCA) with standardized varimax rotation was used to separate interrelationships into statistically independent basic components. In PCA, eigenvectors were calculated to determine the contribution of each variable to the separation of the populations. An analysis of variance (one-way anova) was performed in order to test the main effects of populations on the scores of the first three factors extracted in the PCA.

In addition, we performed a discriminant analysis on the total data set to identify the multivariate relationships among the morphometric traits, and their changes between the populations. The scatter plot of the discriminant scores corresponding to each case of each population in the multivariate space, as defined by the first two discriminant functions, was provided for visualization of multivariate phenotypic variations. The statistical program SPSS (version 11.5 and 16) was used for all the analyses.

The total within-population plasticity (Pl) was calculated for each parameter using the smallest and greatest mean values Pl = 1 – (x/X), where x is the smallest value and X is the largest value for any given leaf measure (Ashton et al., 1998; Bruschi et al., 2003).

Results

Means, standard deviation and coefficient of variation (CV) for fourteen leaf parameters in chestnut trees of three natural populations are showed in Table 2. PCA was applied on all 14 morphometric traits. The eigenvalues, proportion of variance and cumulative proportion of the principal components are presented in Table 3. The first four principal components accounted for 85% of the total variance of all traits whereas the other components comprised a small percentage of total variation

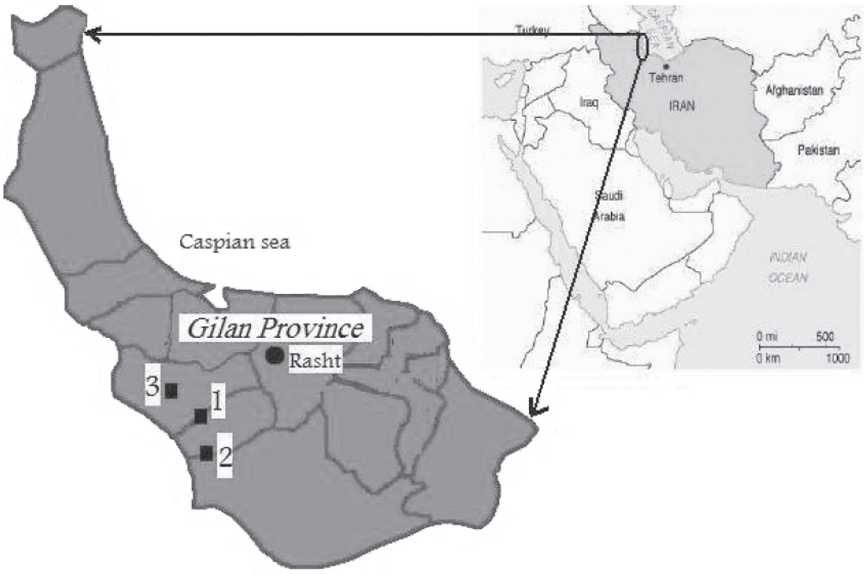


Fig. 1. Location of sampling areas in Hyrcanian forest (in the north of Iran). (1) Siamazgi Population; (2) Visrod population; (3) Ghalerodkhan Population. Distance between 1 and 2: 12 km. Distance between 1 and 3: 10 km. Distance between 2 and 3: 25 km

Table 1. Characteristics of *Castanea sativa* populations studied

Population	Longitude	Latitude	Altitude [m]	Soil type
Siamazgi	49°18'N	37°4'E	200–400	Forest Brown Soils/Low Ph
Visrod	49°15'N	37°15'E	200–500	Forest Brown Soils/ Low Ph
Ghalerodkhan	49°14'N	37°5'E	350–500	Forest Brown Soils/ Low Ph

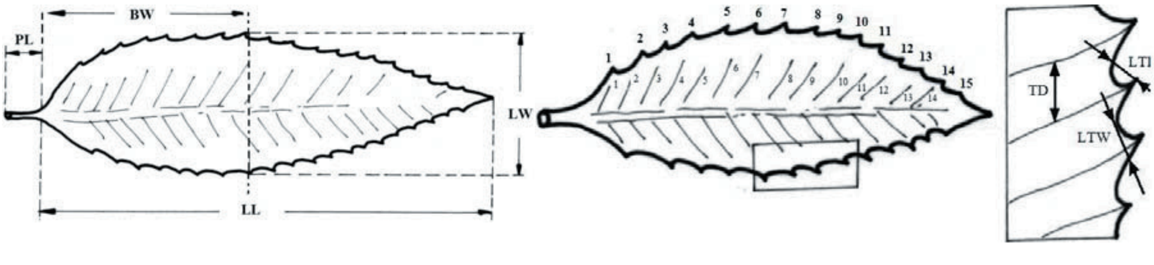


Fig. 2. Presentation of the assessed leaf morphological variables. Lamina length (LL). Lamina width (LW). Petiole length (PL). Distance from leaf base to the leaf maximum width (BW). Leaf tooth width (LTW). Leaf tooth length (LTL). Tooth distance (TD). Teeth (count variable) in bold numbers and vein (count variable) in non bold numbers

(15%). Sixty percent of the total variance could be observed in the first two principal components, indicating a high degree of correlation among the characteristics analyzed. Separate percentages of variation attributed to the first four components by decreasing order are 31%, 29%, 14% and 11%. PC1 was negatively related to LW, TI, LL/PL and BW/BL and positively correlate with PL. PC2 was positively related with LL, V, T, TD and LL/LW. PC3 was positively related with BW and negatively with LL/BW while PC4 was negatively related with LTW and LTI.

Variance analysis presented in Table 4 shows that significant variance among morphometric traits was attributable to differences between the populations. Varia-

Table 2. Means, standard deviation and CV for fourteen leaf parameters in chestnut trees in three natural populations of Hyrcanian forest (in the north of Iran). (Variable abbreviations are explained in the text and Fig. 2.)

	Siamazgi			Visrod			Ghalerodkhan		
	Mean	St. deviation	CV	Mean	St. deviation	CV	Mean	St. deviation	CV
LL [cm]	22.7	1.07	4.7	21.3	1.49	6.9	23.4	0.58	2.4
LW [cm]	7.6	0.54	7.1	8.2	1.09	13.2	7.2	0.24	3.3
BW[cm]	14.8	0.92	6.2	14.1	1.52	10.7	14.1	0.98	6.9
PL [cm]	1.3	0.11	8.4	1.3	0.12	9.2	1.5	0.20	13.3
V	20.8	1.29	6.2	19.4	1.84	9.4	22.9	0.77	3.3
T	19.7	1.25	6.3	19	2.06	10.8	22.4	0.99	4.4
LTW [cm]	0.7	0.03	4.2	0.7	0.05	7.1	0.7	0.02	2.8
LTI [cm]	0.3	0.01	3.3	0.3	0.01	3.3	0.3	0.02	6.6
TI [cm]	2.2	0.17	7.7	2.1	0.13	6.1	2.1	0.17	8.0
TD [cm]	1.07	0.05	4.6	1.03	0.06	5.8	0.9	0.04	4.4
LL/LW	3.01	0.27	8.9	2.6	0.27	10.3	3.2	0.14	4.3
LL/PL	17.6	1.54	8.7	16.7	2.31	13.8	16.02	1.64	10.2
LL/BW	1.5	0.03	2	1.5	0.04	2.6	1.6	0.09	5.6
BW/PL	11.4	0.95	8.3	11	1.58	14.3	9.6	1.26	13.1

Table 3. Correlation coefficients between leaf traits of the *C. sativa* trees and four principal components analysis and proportion of variability by the first four components, at 5% probability level. Only significative coefficients at p < 0.05 are shown.

	Factor 1	Factor 2	Factor 3	Factor 4
LL [cm]		0.87*		
LW [cm]	–0.86*			
BW [cm]			0.88*	
PL [cm]	0.95*			
V(counted variable)		0.90*		
T(counted variable)		0.89*		
LTW [cm]				–0.80*
LTI [cm]				–0.82*
TI [cm]	–0.61*			
TD [cm]		0.79*		
LL/LW		0.79*		
LL/PL	–0.88*			
LL/BW			–0.77*	
BW/PL	–0.82*			
Eigenvalue	4.47	4.15	2.09	1.55
Explained variance	0.31	0.29	0.14	0.11
Cumulative variance [%]	31	60	74	85

tion due to populations was significant in the first three principal components extracted ($P < 0.05$, Table 4). A post-hoc analysis compared factor scores, and revealed nuances in the differences between the populations (Table 5). In the first factor, the Ghalerodkhan Population was significantly different from Siamazgi and Visrod populations whereas these two populations did not differ from each of other. In regards to the second factor, all three populations differed significantly from each other. In regards to the third factor, the Ghalerodkhan Population showed no significant difference from the Visrod Population (Table 5).

We performed a discriminant analysis on the data for all populations. Two ones of all roots (discriminant functions) had significantly associated eigenvalues (Table 6). The population cases were plotted on root1/ root2 (Fig. 3). Function 1 accounting for 31% of total variance clearly separates the Siamazgi Population from the other two. Function 2 represents another 29% of the total variance, and separates the Ghalerodkhan Population from the other two.

Results of classification discriminant analysis showed a high percentage of correctly classified cases for all actual populations (in total 93%, Table 7).

The low plasticity was found in most of the characters. Particularly, tooth distance (TD) and leaf length/ distance from leaf base to the widest point (LL/BW) showed very low values (Fig. 4).

Discussion

The main finding of this study is the high morphological differentiation among *Castanea sativa* stands in Hyrcanian forest located in north of Iran. This is a statistically robust result because we have transformed all the measured variables in order to account for ontogenetic factors related to the variable leaf size. As demonstrated by several studies (Blue and Jensen, 1988; Bruschi et al., 2003) most trees produce a wide range of leaf sizes as a result of positional effects and epigenetic factors (i.e., micro-environmental differences within the population). If the variation observed in linear measures (Fig. 2) was only a function of the difference existing among leaf sizes, then the analysis of residuals carried out from linear regression against the total size should highly limit the number of significant effects. Thus, the observed pattern of morphological variation should have strictly reflected the real genetic and adaptive differences among the studied populations. These findings coincide with the results of Aravanopoulos et al. (2005) who examined leaf variability in *Castanea sativa* populations in Greece.

Table 4. One-way Analysis of Variance carried out on each factor extracted

		SS	G	MS	F	P
Factor 1	Population	7.892	2	3.946	4.401	0.016
	Error	51.107	57	0.896		
Factor 2	Population	25.951	2	12.975	22.379	0.000
	Error	33.048	57	0.579		
Factor 3	Population	15.347	2	7.673	10.020	0.000
	Error	43.652	57	0.675		
Factor 4	Population	2.915	2	1.457	1.481	0.235
	Error	56.084	57	0.983		

Table 5. Post- hoc comparison LSD (Least Significant Differences) test

		Visrod Population	Ghalerodkhan Population
Factor 1	Siamazgi Population	0.631	0.025
	Visrod Population		0.007
Factor 2	Siamazgi Population	0.002	0.0009
	Visrod Population		0.0000
Factor 3	Siamazgi Population	0.003	0.00005
	Visrod Population		0.206

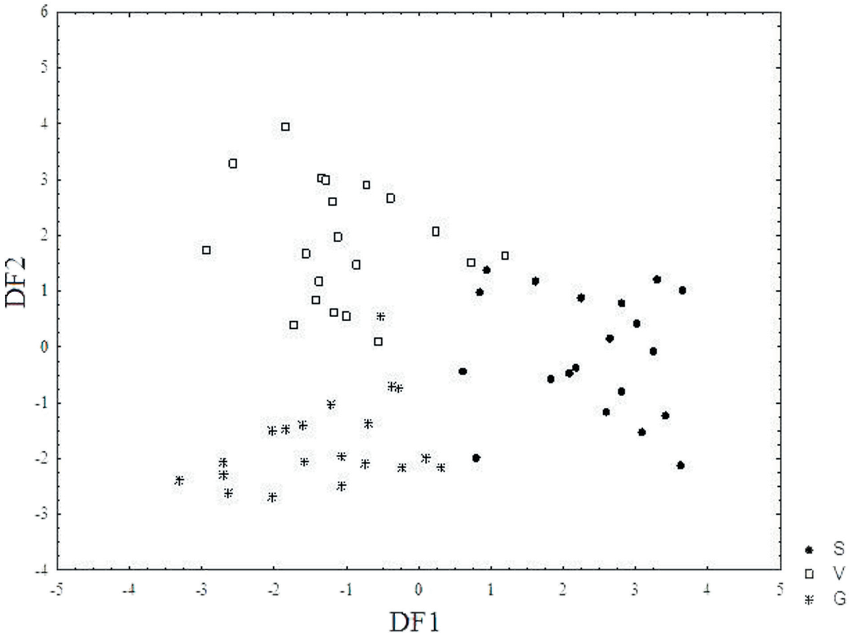


Fig. 3. Scatter plot of the discriminant analysis. Discriminant scores of the considered cases from different populations in the plot of the first two discriminant functions (DF1, DF2) are shown on the axes. (S) Siamazgi Population; (V) Visrod Population; (G) Ghalerodkhan Population

Table 6. Standardized coefficients and characteristics of discriminant analysis for first two discriminant functions (DF1, DF2)

	DF1	DF2
TI	0.98	0.06
TD	0.04	1.42
LL/BW	–1.47	0.05
N	0.32	–0.71
T	–0.40	0.11
BW	3.84	2.15
LTI	0.06	–0.21
LL/PL	11.34	3.15
LW	–2.81	1.72
LL	–3.79	–2.26
BW/PL	–9.18	–3.12
Autoval	2.95	2.26
Prop. Cum	0.56	1.00
Eigenvalue	2.95	2.26
Wilks Lambda	0.07	0.30
CHi-Sguare	133.01	61.50
p-level	0.000	0.000

Table 7. Number and percentage of cases correctly classified by discriminant analysis

	Siamazgi	Visrod	Ghalerodkhan	% of correct cases
Siamazgi	18	1	1	90
Visrod	1	19	0	95
Ghalerodkhan	0	1	19	90
Total	19	21	20	93

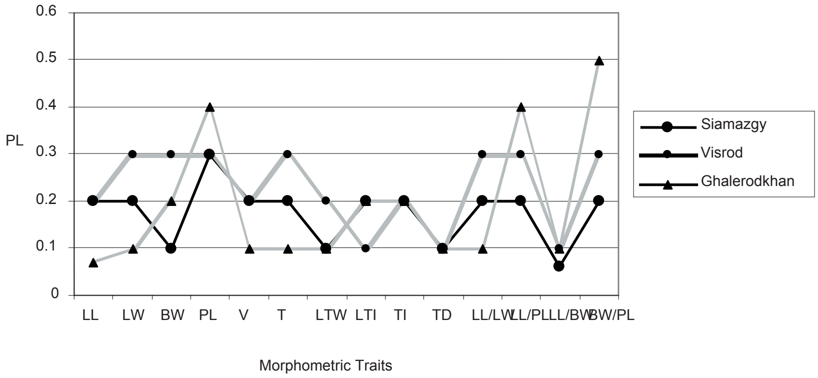


Fig. 4. Plot of plasticity (Pl) for all characters and characters ratios studied measured

Also Ertan (2007), Bolvansky and Uzik (2005) and Aravanopoulos et al. (2001) reported significant differences between accessions and populations of *C. sativ*a based on leaf and fruit morphology. In general, there are several studies using different morphological and molecular techniques for estimating diversity of chestnut populations (Villani et al., 1999; Pereira-Lorenzo et al., 1996; Orgauzie et al., 1998; Mancuso et al., 1999; Goulao et al., 2001; Yuqing and Dane, 2003). However, none of the reported morphological studies used a statistical approach in order to correct for allometric and epigenetic effects.

Our results clearly show that the highest mean value in the majority of characters studied, belonged to Ghalerodkhan individuals, especially lamina length, petiole length, teeth (count variable) and vein (count variable), although climate (rainfall and temperate) and soil type are similar in the other two studied stands. In contrast to the European chestnut, as studied in other countries (Aravanopoulos et al., 2005; Ertan, 2007), the leaf size in the Iranian chestnut is larger but length of the petiole is shorter.

In our PCA, the major proportion of variation (60%) was accounted for the first two principal components. Based on the analysis of the eigenvectors from the PCA it can be concluded that the first three components separate populations by inferring differences in leaf size (LL, LW, and BW), while the fourth component did not separate populations by inferring differences in leaf size. In PCA 4, populations were separated by inferring differences in teeth variables.

In this study, lamina size variables (LL, LW, BW and PL) and lamina shape parameters appear to be more important compared to the other parameters, since their high loading characterizes the low space eigenvectors. Similarly, leaf size and shape variables have been used repeatedly in the literature for similar studies – with a notable success (Rajora et al., 1991; Ahmed and McNeil, 1996; Khasa and Bousquet, 2000; Aravanopoulos et al., 2005).

Low values in plasticity were observed among all of the characteristics studied. In particular, tooth distance (TD) and leaf length/distance from leaf base to the widest point (LL/BW) showed values lower than the others. Because the populations studied are situated in the Hyrcanian region within the same biogeographical ranges, isolation and environmental homogeneity could explain the low plasticity – because plant phenotypic plasticity involves changes in physiology, morphology or development of the same genotype growing in different environments (Gianoli and Gonzalez-Teuber, 2005). However, the mere observation of plasticity in a phenotypic trait does not necessarily imply that the response is adaptive (Schwaegerle and Bazzaz, 1987; Sultan, 1995). In controlled field trial conditions, there have been no reports of a lack of plasticity for any morphometric characters such as was evidenced in this study. Further investigation is needed to compare our findings with those in controlled field conditions.

In general, our results indicate considerable leaf variation in the populations studied. Moreover, we can conclude that leaf parameters are suitable variables to detect levels of phenotypic variability among Chestnut natural populations. Future studies should be focused on nut morphology, enzyme electrophoresis and molecular markers in natural Chestnut populations in Iran.

The high diversity observed in the populations studied is very important for the conservation of the species genetic resources, and it should be also considered by botanists and taxonomists.

Acknowledgement

We wish to express our thanks to Mona Nazary and M.R. Akbarian for their help in providing materials and measuring leaves. The authors also extend many thanks to Dr Milan Bolvansky (Institute of Forest Ecology of the Slovak Academy of Sciences, Nitra, Slovakia), Dr Engin Ertan (Adnan Menderes University – Turkey) and Dr Cecilia Hennessy (Purdue University) for their valuable recommendations.

References

Ahmad, M., Mc Neil, D.L. 1996. Comparison of crossability, RAPD, SDS-PAGE and morphological markers for revealing genetic relationships within and among Lens species. *Theor. appl. Genet.*, 93: 788–793.

Aravanopoulos, F.A. 2005. Phenotypic variation and population relationships of chestnut (Castanea sativa) in Greece, revealed by multivariate analysis of leaf morphometrics. *Act hort.* 693: 230–240.

Aravanopoulos, F.A., Drouzas, A.D., Alizoti, P.G. 2001. Electrophoretic and quantitative variation in chestnut (Castanea sativa Mill.) in Hellenic populations in old-growth natural and coppice stands. *For. Snow Landsc. Res.*, 76 (3): 429–434.

ashton, P.M.S., Olamder, L.P., Berlyn, G.P., Thadani, R., Cameron, I.R. 1998. Change in leaf structure in relation to crown position and tree size of Betula papyrifera within fire region stands of interior cedar-hemlock. *Can. J. Bot.*, 76: 1180–1187.

Blue, M.P., Jensen, R.J. 1988. Positional and seasonal variation in Oak (Quercus: Fagaceae) leaf morphology. *Am. J. Bot*., 75: 939–947.

Bolvansky, M., Uzik, M. 2005. Morphometric variation and differentiation of European Chestnut (Castanea sativa Mill.) in Slovakia. *Biologia (Bratislava)*, 60 (4): 423–429.

Bruschi, P., Grossoni, P., Bussotii, F. 2003. Within- and among-tree variation in leaf morphology of Quercus petraea (Matt.) Liebl. natural populations. *Trees*, 17: 164–172.

Cousens, J. E., 1963. Variation in some diagnostic characters of the sessile and pedunculate oaks and their hybrids in Scotland. *Watsonia*, 5: 273–286.

Diamandis, S., Perlerou, C. 1996. Biological control of Chestnut blight and resin top disease of Scots pine in Greece. In *Proceedings of the Greek-Bulgarian Conference*. Drama: GEOTTE Publ., p. 93–99.

Dickinson, T.A., Parker, W.H., Strauss, R.E. 1987. Another approach to leaf shape comparisons. *Taxon,* 36: 1–20.

Ertan, E. 2007. Variability in leaf and fruit and in fruit composition of Chestnut (Castanea sativa) in the Nazilli region of Turkey. *Genet. Resour. Crop. Evol.*, 54: 691–699.

Gianoli, E., González-Teuber, M. 2005. Environmental heterogeneity and population differentiation in plasticity to drought in Convolvulus chilensis (Convolvulaceae). *Evol. Ecol.*, 19: 603–613.

Goulao, L., Valdiviesso, T., Santana, C., Oliveira, C.M. 2001. Comparison between phonetic characterizations using RAPD and ISSR markers and phenotypic data of cultivated Chestnut (Castanea sativa Mill.). *Genet. Resour. Crop Evol*., 48 (4): 329–338.

Ishida, T.A., Hattori, K., Sato, H., Kimura, M.T. 2003. Differentiation and hybridization between Quercus crispula and Q. dentata (Fagaceae): Insights from morphological traits, amplified fragment length polymorphism markers, and leaf-miner composition. *Am. J. Bot*., 90 (5): 769–776.

Jazireie, M.H. 1961. *Chestnut (a tree for Iran)*. Iranian forestry press. 14 p.

Khasa, P.D., Bousquet, J. 2001. Multivariate analysis of allozyme and morphometric variability in Racosperma auriculiformae and R. manguim. *Silvae Genet*., 50: 191–199.

Kremer, A., Dupouey, J.L., Deans J.D., Cotterell, J., Csaikl, U., Finkeldey, R., Espinel, S., Jensen, J., Kleinschmit, J., Van Dam, B., Ducousso, A., Forrest, I., De Heredia, U.L., Lowe, A.J., Tutkova, M., Munro, R.C., Stenhoft, S., Badeau, V. 2002. Leaf morphological differentiation between Quercus robur and Quercus petraea is stable across western European mixed oak stands. *Ann. Forest Sci*., 59: 777–787.

Lang, P., Huang, H. 1999. Genetic variation and population structure of three endemic Castanea species in China. *Act. Hort*., 494: 269–276.

Mancuso, S., Ferrini, F., Nicese, F.P., 1999. Chestnut (Castanea sativa Mill.) genotype identification: an artificial neural network approach. *J. Hort. Sci. Biotechnol.*, 74 (6): 777–784.

Neophytou, C.H., Palli, G., Dounavi, A., Aravanopoulos, F.A. 2007. Morphological differentiation and hybridization between quercus alnifolia Poech and Quercus coccifera L. (Fagaceae) in Cyprus. *Silvae Genet*., 56 (6): 271– 277.

Olsson, U. 1975. A morphological analysis of phenotypes in populations of Quercus (Fagaceae) in Sweden. *Bot. Not*., 128: 55–68.

Oraguzie, N.C., Mcneil, D.L., Peterson, A.M., Chapman, H. 1998. Comparison of RAPD and morphonut markers for revealing genetic relationships between Chestnut species and New Zealand Chestnut selection. *N.Z. J. Crop Hort. Sci*., 26: 109–115.

Pereira-Lorenz, S., Fernandez-Lopez, J., Moreno-Gonzales, J. 1996. Variability and grouping of Northwestern Spanish Chestnut cultivars. II. Isoenzymatic traits. *J. Am. Soc. Hort. Sci*. 121: 190–197.

Poorbabaei, H. 2008. *Stand structure and spatial pattern of sweet Chestnut (Castanea sativa) trees in the Gilan forests, North of Iran*. Paper presented at the Global Conference on Global Warming, July 6–10, Istanbul, Turkey.

Rojara, O.P., Zsuffa, L., Dancik, B.P. 1991. Allozyme and leaf morphological variation of eastern Cottonwood at the Northern limits of its range in Ontario. *J. For. Sci*., 37: 668–702.

Rutter, P.A., Miller, G., Payne, J.A., 1990. Chestnut. In Moore J.N, Ballington J.R. (eds). *Genetic resources of temperate fruit and nut crops*. Act. Hort., 290. Wageningen: The International Society for Horticulture Science, p. 761–788.

Schwaegerle, K.E., Bazzaz, F.A. 1987. Differentiation among nine populations of Phlox: response to environmental gradients. *Ecology*, 68: 54–64.

Sultan, S. E., 1995. Phenotypic plasticity and plant adaptation. *Acta bot. neerl.*, 44: 363–383.

Villani, F., Sansotta, A., Cherubini, M., Cesaroni, D., Sbordoni, V., 1999. Genetic structure of natural populations of Castanea sativa in Turkey: evidence of hybrid zone. *J. Evol. Biol.*, 12: 233–244.

Yuqing, F., Dane, F., 2003. Allozyme variation in endangered Castanea pumila var. pumila. *Ann. Bot.*, 92: 223–230.

Fenotypická variabilita prirodzených populácií gaštana (*Castanea sativa* Mill.) v pohorí Hyrcanian (severný Irán) na základe morfometriky listov

Súhrn

Gaštan jedlý je rozšírený v pohorí Hyrcanian na severe Iránu ako okrajová drevina. Je to hospodársky významná drevina z hľadiska produkcie dreva a plodov a preto jej zachovanie je veľmi dôležité. Neexistujú však informácie o variabilite populácií gaštana v Iráne. Cieľom práce bolo preskúmať variabilitu morfológie listov pri troch prirodzených populáciách gaštana. Pri 20 stromoch v každej populácii bolo zobraných po 40 listov. Pri každom liste bolo zaznamenaných 9 parametrov (dĺžka čepele, šírka čepele, dĺžka stopky, vzdialenosť od bázy listu k maximálnej šírke listu, šírka zúbku, dĺžka zúbku, vzdialenosť medzi zúbkami, počet žiliek, počet zúbkov) a 4 parametre boli vypočítané (dĺžka listu / šírka listu, dĺžka listu / dĺžka stopky, dĺžka listu / vzdialenosť od bázy listu k maximálnej šírke listu, vzdialenosť od bázy listu k maximálnej šírke listu / dĺžka stopky). Na nahradenie pôvodného súboru premenných súborom nových, vzájomne nekorelovaných, umelých premenných bola použitá metóda hlavných komponentov (PCA). Väčšina variability (85 %) sa dala vysvetliť prvými štyrmi komponentmi a veľkosť listov bola premenná s najväčšou váhou pri vlastných vektoroch. Hodnoty hlavných komponentov z PCA boli použité pri jednoduchej analýze variancie. Pri väčšine faktorov sa ukázali štatisticky významné rozdiely medzi populáciami. Výsledky diskriminačnej analýzy ukázali na vysoké percento správne klasifikovaných prípadov vo všetkých aktuálnych populáciách (v priemere 93 %). Parametre plasticity listov vykazovali nízke hodnoty pri všetkých sledovaných znakoch. Môže sa zhrnúť, že znaky listov sú vhodné premenné na detekciu úrovne fenotypickej variability medzi prirodzenými populáciami gaštana. Vysoká variabilita pozorovaná v sledovaných populáciách je dôležitá pre uchovanie genetických zdrojov druhu.

Received January 4, 2010
Accepted March 13, 2010

Chronicle

We recall Assoc. Prof. Ing. Dr. h. c. František Benčať, DrSc. (18. 9. 1929–17. 1. 2010)

On January 20, 2010, many representatives of the botanic public as well as the wide public of Topoľčianky said the last goodbye to Assoc. Prof. Ing. Dr. h. c. František Benčať, DrSc. We have lost an excellent charismatic man, enthusiastic and creative up to his last days. As the Director of the Arboretum Mlyňany – the Institute for Woody Plant Biology of the Slovak Academy of Sciences, (1954–1989), F. Benčať made it an important scientific institution focussing on comprehensive research on woody plants. The institution consists of five research departments (Systematic, Ecology, Physiology, Genetics, Landscape building). He sacrificed all his life to scientific research in area of botany, primarily woody plant biology – with a special focus on exotic woody plants introduced into Slovakia. His emblematic species was the sweet chestnut (*Castanea sativa* Mill.). F. Benčať also provided a considerable contribution to the woody plants collections in the Arboretum Mlyňany. Under his leadership, the number of the taxons in the Arboretum increased more than four times. At present, with 2,200 species, it belongs to the richest subjects of this kind in the Central Europe.

F. Benčať applied his valuable scientific and management experience also in protection of nature, landscape as well as the life environment as a whole. The results of these activities have been summarised in the “Concepts of protection and building of settlement greenery in Slovakia “and in the “Bio-project Jelšava“. His significant contribution to the issue of introduction and re-introduction of exotic woody plants into Slovakia is presented in the “Atlas of distribution of exotic woody plants across Slovakia and zoning for their cultivation “, awarded in 1986 with the “National Award of the Slovak Republic “.

Assoc. Prof. Ing. František Benčať, DrSc. had several important functions in scientific and controlling structures of the former Czechoslovak Academy of Sciences, Slovak Academy of Sciences, universities and national authorities. For many years, he was the Head of the Botanical Society of the Slovak Academy of Sciences and the Editor in Chief of the Journal Folia dendrologica (1974–1989). His scientific, organisational and social activities were given 53 awards. As the most precious, he considered the honorary citizenship of his native village of Kozárovce. Very rich is also the set of his publications representing 110 original scientific works, 70 scientific contributions and 51 presented papers. He was active in purpose-oriented education of young scientific workers, several of whom are at present outstanding scientists and teachers.

The absence of Doc. Ing. František Benčať, DrSc. means for the Slovak scientific community absence of an irreplaceable expert in botany and a devoted, nature-loving man.

Honour to his memory.

Ferdinand Tokár
Kalinčiakova 3
953 01 Zlaté Moravce
Slovak Republic

Instructions for authors

Folia oecologica is a journal devoted to publishing original scientific papers from the fields of ecology of forest ecosystems, communities and populations of plants, fungi and animals associated with forest environment and also the ecology of woody plants growing in both forest and non-forest environment, human settlements included.

The journal also publishes short communications, methodological and survey papers in the area, book reviews, personalia and information about scientific events. The manuscripts are submitted to reviewers for evaluation of their significance.

Manuscript layout. The manuscripts should be written in English, well-arranged, not exceeding a maximum extent of 20 pages, including tables and figures. The authors are responsible for the quality of the text, manuscripts written in poor English will be returned. Please, send two copies of the manuscript (A4 format, type size 12 font Times New Roman, double-space lines, 3 cm margins on each edge of the page) together with all figures and tables (each on a separate sheet) to the editorial office. Avoid dividing the words, smoothing right text margins; do not define the styles and paragraphs. Do not use either spacing or tabulator for beginning of a paragraph. If the paper has been submitted for publication, send two printed copies and one copy in electronic form (CD or DVD) as a Microsoft Word file (DOC, or RTF format).

An original scientific paper should comprise: 1. The title. 2. The author's name: full first name and second name. 3. Address: complete address and e-mail address (if available) of all the authors. 4. Abstract: in one paragraph, without references to tables, figures and literature, not exceeding 15 lines (900 characters). 5. Key words (maximum 6). 6. Introduction. 7. Material and methods. 8. Results. 9. Discussion (or Results and discussion). 10. Acknowledgement. 11. References. 12. Summary in Slovak (or in Czech): not exceeding an extent of one page, including the title of the paper in Slovak.

In the papers, it is necessary to use SI symbols. Non-integer numbers should be provided with a decimal point, (e.g. 1.7), not a comma (1,7), the thousands (with exception of years) are separated with a comma: 5,600. The variables in mathematical formulae and expressions should be written in italics, the symbols for functions and constants in the normal font, the matrices in bold capitals, the vectors in bold small letters. Latin names of genera, species, subspecies and varieties are written in italics, the name of the author of the description (or his abbreviation) normally: e.g. *Lymantria dispar* (Linnaeus, 1758), *Lymantria dispar* (L.), *Abies cephalonica* Loud. var. *graeca* (Fraas) Liu. The names of cultivars are written normally, e.g. *Olea europea* L. cv. Chalkidikis. All the tables and figures must be referred to in the text: Table 1, Tables 2–4, Figs 2–4. The authors are asked to indicate placing of the tables and figures on the text margins.

Literature citations. The literature cited in the text should conform to the following patterns: one author – FUNKE (1971) or (FUNKE, 1971), two authors – SOKAL and ROHLF (1995) or (SOKAL and ROHLF, 1995), three and more authors – ALSTAD et al. (1982) or (ALSTAD et al., 1982). More than one work written by the same author is to be distinguished with small letters appended after the year: NOVÁK (1950a, 1950b). If the document does not contain either the name of the responsible person or the corporation and if it is not possible to conclude about the author with certainty from other authorities, the work should be cited as written by an ANONYMUS.
References in the final list are to be provided with the full title and names of all authors; ordered alphabetically and according to the publication year. Latin names of genera, species and sub-species cited in the list of references are to be written in standard type. The titles are to be cited in the original language appended by an English translation (in brackets). The issue number (except the volume number) should be given (in parentheses) only in the case when the volumes are not paginated continually. The titles of periodicals should be cited in shortened form, according to the international rules, conform to the World list of scientific periodicals. The basic instructions can be found in Bojňanský et al. (1982) Periodiká z oblasti biologicko-poľnohospodárskych vied, ich citácia a skratky [Periodicals in area of biological and agricultural sciences, their citations and abbreviations]. Bratislava: Slovenská spoločnosť pre poľnohospodárske, lesnícke a potravinárske vedy pri SAV. 704 p. In the case of a possible ambiguity, cite the periodical under the full name. Titles in languages not using the Latin alphabet should be transliterated keeping with the British Standard 2979 (in the case of the Cyrilic e.g. ж = zh, х = kh, ц = ts, ч = ch, ш = sh, щ = shch, ю = yu, я = ya). (The basic rules can be found e.g. in Bojňanský et al. 1982).

The following form of citation should be used:

Work in a periodical

Sharov, A.A., Liebhold, A.M., Ravlin, F.W. 1995. Prediction of gypsy moth (Lepidoptera: Lymantriidae) mating success from pheromone trap counts. *Envir. Ent*., 24: 1239–1244.

Eiberle, K., Nigg, H. 1984. Zur Ermittlung und Beurteilung der Verbissbelastung. *Forstwiss*. *Cbl*., 103: 97–110.

Book

Szujecki, A. 1983. *Ekologia owadów leśnych* [Ecology of forest insects]. Warszawa: Państwowe Wydawnictwo Naukowe. 604 p.

Miller, J.R., Miller, T.A. (eds) 1986. *Insect-plant interactions*. New-York: Springer-Verlag. 342 p.

Work published in a book or in a proceedings

Basset, Y., Springate, N.D., Aberlenc, H.P., Delvare, G. 1997. A rewiew of methods for sampling arthropods in tree canopies. In Stork, N.E., Adis, J., Didham, R.K. (eds). *Canopy arthropods*. London: Chapman & Hall, p. 27–52.

Ciberej, J., Kováč, G., Bilá, A. 1999. Faktory ovplyvňujúce početný stav kamzíka vrchovského v TANAP-e [Factors influencing game populations in chamois (Rupicapra rupicapra L.) in the High Tatra National Park]. In Koreň, M. (ed.). *Päťdesiat rokov starostlivosti o lesy TANAP-u. Zborník referátov z konferencie*. Poprad: Marmota Press, p. 111–116.

Dissertation

Chromová, L. 2002. *Pôdne a vegetačné zmeny lesných spoločenstiev okolia obce Brusno (Veporské vrchy)* [Changes in soils and vegetation of forest communities of the Brusno village (the Veporské Mts.)]. PhD thesis. Bratislava: Comenius University, Faculty of Natural Sciences. 122 p.

Tables. The tables should be submitted on separate sheets, not included into the text. The sheets must not be folded. The tables are to be numbered, each after other, with Arabic numerals (Table 1, Table 2…). The text in the caption should always begin with a capital letter. The tables can be self-explicable, not requiring references in the text. The numbering and captioning should be placed over the table, commentaries, if any, under the table. Submitted are only tables prepared in Word and Excel, without vertical grid lines. Use the font size 9. Table width should be of one or two text columns (77 and 160 mm) or 235 mm. Avoid doubling the information in tables and plots.

Figures. Submitted are only high-quality drawings, plots and photographs in black, each on a separate A4 sheet. They can be prepared manually or printed with a laser or an ink printer. Please use only hatching, not shading. Avoid three-dimensional graphs, if possible. In captions use the Arial font. The font size should not exceed 11, the recommended size is 9. If possible, use the unified size. Figure width should be 77, 160 or if necessary, 235 mm. The lines must be well clean-cut and the written text must be distinctly readable also after the diminution. For the electronic version, only MS Excel is acceptable. The backside of sheet should be provided with the number of the figure and the author's name. The graphs and ink drawings must be self-explicable and readable with captions and appended keys of symbols only, without necessity to seek explanations in the text.

Off-prints. Each author and co-authors will obtain one electronic copy of the published paper.

Editorial office. Institute of Forest Ecology SAS, Centre of Scientific Information – Library, Štúrova 2, 960 53 Zvolen, Slovak Republic, e-mail: knizuel@savzv.sk Manuscripts should be sent to the editorial office.