Analysis of physiological parameters of spruce trees as indicators of spruce dieback in the Spiš region

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Abstract

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This contribution is dealing with the large-scale dieback of spruce stands in the region Horný Spiš. The physiology of Norway spruce (*Picea abies* L. Karst) in this area is influenced and limited by a range of natural and anthropogenic ecological factors, acting in general in interactive way. The work summarises the results of an eco-physiologically oriented research evaluating physiological and so also health status of the relevant spruce stands. The research was running in year 2004 on two monitoring plots selected at the locality "Hliníky" in the region Horný Spiš. One plot showed symptoms of acute stand decomposition, the other lacked visible damage symptoms. The age of spruce trees on both plots was 80 years (adult trees). The analysis was focussed on appropriate indicators – biomarkers indicating damage to the spruce assimilatory apparatus as a tool for solving the issue of massive dieback of spruce stands. There have been processed the results of measurements of parameters of chlorophyll *a* fluorescence and the values of concentrations of assimilatory pigments.

Key words

eco-physiology, multiple stress, dieback, Norway spruce, Spiš

Introduction

Since 30 years ago, the health state of spruce stands has been recording a dramatic decline over the whole European continent. In Slovakia, there have been damaged extensive areas in the regions Orava, Kysuce, Spiš and in the Tatra Mts.

The physiology of Norway spruce (*Picea abies* L. Karst) is influenced and limited by a range of abiotic and biotic factors, acting in general interactively: drought, wind, snow, frost, acid litter, insects, fungal diseases, management methods and airborne acid pollutants. The rapid dieback of trees and whole stands was also accelerated by extreme weather connected with the global climate change. The result is multiple stress that can cause fading, diseasing and dieback of individual trees up to decomposition of the whole stands. It is high important to seek ways how to indicate stress load to forest woody plants and stands, determine latent diseases and damage because early diagnostic of the disease can prevent from passing to more progressive stages. The goal of eco-physiological research on damage to forest woody plants is to recognise various mechanisms how the stressing factors disturb physiology of trees, shrubs and whole forest ecosystems at a specific site. Bio-indication of stress load is possible at various levels of biological systems and with using a range of physiological and biochemical reactions or parameters – biomarkers. The aim is to obtain reliable diagnostic indicators of the latent damage (Kmeť and Ditmarová, 2003).

Apart from the well recognised and well described types of damage to and decomposition of forest stands, since recently has also been present dieback attacking spruce stands of various age, at various sites. This dieback is not possible to classify to either of the known disturbance patterns according to the symptoms and ecological conditions.

In the frame of solving the APVT project "Analysis of causes and proposal for measures against massive dieback of spruce forest stands in border areas of Northern Slovakia", there has been accomplished a multidisciplinary research on dieback of spruce stands in the regions of Horný Spiš and Kysuce, running under the preliminary working title "Unspecific dieback of spruce stands". It was studied physiological state of spruce trees (transpiration, assimilatory pigments, chlorophyll *a* fluorescence, mineral nutrition, microclimatic characteristics) for different age classes (seedlings, young growth, adult trees). In this contribution we present results of measurements of physiological parameters in adult trees. We are focussing on assimilatory pigments, first of all on measurement of chlorophyll *a* fluorescence – the methods used in bio-indication of stress to forest woody plants.

Material and methods

The assessment of changes to physiology and also to the health status of spruce trees in the studied territory at the locality "Hliníky" in the region Spiš was made on 10 adult sample trees. Five trees were selected from the border of the stand with evident signs of decomposition; five trees were selected from the same plot, inside the stand without visible damage symptoms. The stand age is approximately 80 years.

The locality "Hliníky" Spiš is situated in the Slovenské rudohorie Mts unit Volovské vrchy. The altitude is 950 m asl, exposition S-SW, slope inclination 10%. The parent rock consists of agglomerates. The most frequent soil type at the site is podzolic cambisol. The climate is moderate cold; with a mean annual temperature of 6.8 °C and mean annual precipitation total of 700 mm. The locality belongs to the 5-th forest vegetation tier, group of forest types Abieto-Fagetum. The proportion of spruce is 100%.

Improper species composition of the stand, secondarily altered in profit for spruce and the fact that the spruce is the woody plant least resistant against effects of airborne pollutants are resulting in gradual decomposition of the ecosystems at this locality.

Analyses of chlorophyll a fluorescence

In 2004 we measured parameters of both phases – fast and slow of fluorescence of chlorophyll *a* in one-year old spruce needles (year 2003), on September 27.

Analysis of chlorophyll fluorescence represents a non-destructive and fast method enabling us to gain timely information about physiological activity of leaves and whole plants and about internal structure of their assimilatory organs.

The method is working based on the fact that the light energy exceeding the needs of photosynthetic process is spread either in form of fluorescence or in form of heat. The changes in rate of the photosynthetic process or in the dispersed heat cause total changes in the fluorescence emission. If all the reaction spots of the photosystem II (RC PS II) are closed, 95–97% of the absorbed anergy is converted to heat and 2.5–5% to fluorescence (Bolhar-Nordenkampf and Öquist, 1993). If the assimilatory organ is suddenly irradiated (after having been adapted to the dark), the studied fluorescence induction line is dependent on time (more in Kmeť, 1999). We were focussing on the baseline parameters of the fluorescence phenomenon (F_0, F_m, F_v, F_v/F_m T_m and *Area*) determined with a transportable apparatus – fluorimeter Plant Efficiency Analyser (PEA, Hansatech Ltd, Kings Lynn, UK). The measurements were made after a 30-min adapting period, at a 50% level of intensity of light incidence (2100 μmol m^{-2} s^{-1}) and an interval of 1 second of data recording.

Analyses of assimilatory pigments

In fresh spruce needles (delivered to the laboratory in a portable cold box) we determined concentrations of photosynthetic pigments (chlorophylls *a, b*, total content of carotenoids and their mutual ratios). The chlorophylls and carotenoids were analysed from 80% water solution of acetone with spruce needles homogenised in a homogeniser. The absorbance values were measured spectre-photometrically (apparatus Cintra 6.5, GBS, Australia), the concentrations of photosynthetic pigments were determined with adjusted equations according to Lichtenhalter (1987). Concentrations of chlorophylls *a, b, a + b* and carotenoids *x + c* are given per a unit dry mass amount (mg g^{-1}).

Statistical analyses

The results were processed statistically, with variance analysis, software STATISTICA 5.5. The individual components of the variance corresponding to the known factors were compared with the residual variance, by means of the F-test. The analysis was focussed on the influence of the specified factor – experimental plot on values of parameters of fluorescence of chlorophyll *a* (*Area*, F_v/F_m), on the determined concentrations of the other chlorophylls (chl *a+b*, car *x+c*) and their mutual ratios (chl *a/b*, chl *a+b*/car *x+c*).

Results and discussion

Over the year 2004, we examined contents of chlorophyll *a*, chlorophyll *b* and the total amount of chlorophyll *a+b* in assimilatory organs of adult spruce trees on the control plot without visible damage symptoms and on the plot with remarkable signs of stand decomposition (Table 1).

Several authors (eg Matyssek et al., 1993) suggest that the declining physiological state of spruce needles is connected with decline in chlorophyll content and with decreasing rate of photosynthesis, whereas the values of ratio chl *a*/chl *b* are increasing. On the other hand, the ratio chl *a+b*/car *x+c* shows a decreasing trend. According to Lichtenhalter (1985), the values of ratio of chlorophylls to carotenoids (*a+b/x+c*) in healthy trees (primarily spruces and firs) range within 5–8. If the trees are influenced by stress factors, then the values of this ratio can be within 3–5, whereas the needles can keep their green colouring. In yellow-green needles, these values sink below 3, frequently to 1–2. Consequently, it is possible to provide with the pigments ratios as another biomarker of damage to trees indicating whether the photosynthetic apparatus being under the influence of stress has already been severely damaged or not yet.

In our case, the *a+b/x+c* values are within 3–7, equally in trees growing on both plots: without and with decomposition symptoms. The results manifest a worse performance of the assimilatory apparatus in the examined sample trees on both plots.

From the F-test (variance analysis) performed on the photosynthetic pigments, it is obvious that there is not any significant difference between the two plots at the significance level of 95%.

Consequently, our results show that the different contents of chlorophylls, carotenoids and their mutual ratio are not unequivocal indicators of better physiological status of spruce trees on the control plot in comparison with the trees on the plot with advanced decomposition symptoms. It is important to point out that both plots are situated in the same forest stand, so the damage to their physiological and health status is present on both.

It is well-known that the dynamics of photosynthetic pigment contents in tree assimilatory organs is influenced by a range of environmental factors (natural seasonal changes, differences between the sun and the shade needles, airborne pollutants, drought, extreme temperatures, mineral nutrition and others) (Amundson et al., 1993; Mikkelsen et al., 1996).

The results of many research works confirm that the measurement of chlorophyll *a* fluorescence is the method enabling rapid diagnostic of the tree physiological state. This knowledge provides with a background of correlation between photochemical capacity and some parameters of the induction curve of chlorophyll *a* fluorescence, and, on the other hand, with a high sensitivity of the photosynthetic chain for a number of stress factors.

The parameters F_v/F_m and *Area* have namely the highest description value and reflect most appropriately the state and functioning of the assimilatory apparatus. F_v/F_m corresponds to the maximum quantum yield of the primary photochemical reactions of the Photo-system II (PSII). Its value is lower than 0.725, and it indicates the starting of certain physiological disturbances. The parameter *Area* is a measure of the area above the induction curve between the basal (F_0) and the maximum (F_m) fluorescence. It provides sufficient information about the capacity of the transport chain of electrons in primary photosynthetic processes, and it is close correlated with the contents of assimilatory pigments. It is well-known that the values of these parameters are in general higher in assimilatory organs that are not subjected to negative influence.

Bolhar-Nordenkampf and Götzl (1992) having accomplished a great number of measurements, report the following threshold values of the parameter F_v/F_m: 0.85 – normal, 0.72 – threshold values for disturbances, 0.60 – area of severe but reversible damage, 0.30 – area of severe structural damage.

The evaluation of the baseline parameter F_v/F_m shows that its course follows the pattern recognised in

Table 1. Mean values of concentrations of plastid pigments measured in adult spruce trees on plot with symptoms of acute stand decomposition and without visible symptoms of stand decomposition. Date: 27 September 2004

Plot		Chl *a* [mg g^{-1}]	Chl *b* [mg g^{-1}]	Chl *a/b* [mg g^{-1}]	Chl *a+b* [mg g^{-1}]	Car *x+c* [mg g^{-1}]	Chl *a+b*/car *x+c* [mg g^{-1}]
With vds	average	1.65	0.57	2.91	2.22	0.44	5.01
	STD	0.28	0.11	0.25	0.39	0.07	0.25
	sx	0.13	0.05	0.11	0.17	0.03	0.11
Without vds	average	1.36	0.51	2.89	1.87	0.37	5.01
	STD	0.39	0.25	0.57	0.62	0.06	1.12
	sx	0.18	0.11	0.26	0.28	0.03	0.50

With vds – the stand with visible damage symptoms
Without vds – the stand without visible damage symptoms

the assimilatory pigments. It points out gradually worsening physiological state of assimilatory apparatus in the selected adult sample trees (decreasing F_v/F_m), both on the plot without and with symptoms of acute stand decomposition. These results confirm that physiological damage to the needles on both plots is followed by rapid defoliation and that the residual assimilatory apparatus is not able to supply the given tree with necessary organic materials.

Fig 1 illustrates the course of parameters F_v/F_m and *Area* measured on plots with different decomposition grade. From the comparisons between F_v/F_m values performed by means of variance analysis it follows that the differences of the values of this parameter between the plots with different decomposition stage are not statistically significant ($p > 0.05$). A statistically insignificant difference between the plots was also recorded for the parameter *Area*.

The results of a lot of research works as well as our results confirm that the measurements of physiological parameters (assimilatory pigments concentrations, chlorophyll *a* fluorescence) enable us to analyse more rapidly the physiological and health state of trees.

Křístek (1996) suggests that the dieback of forest woody plants will be caused by their weakening and physiological disturbances. This statement is not only crucial for orientation of further research on dieback of woody plants, but it also presents another question – which are the actual causes of the physiological disturbances.

Conclusions

The worsening health state of forest woody plants and of their dieback is still a topical issue, unfortunately. The results presented in this contribution are a part of more comprehensive multidisciplinary research on dieback of spruce forest stands in the Horný Spiš region. The research was oriented at study of physiological state of spruce trees in all age categories (seedlings, young growth, mature stand), in connection with site conditions. The results of measurements of physiological parameters in adult spruce trees manifest a lower level of photosynthetic process in the assimilatory apparatus and insufficient nutrient supply to the examined spruce sample trees growing on both plots – without and with visible symptoms of acute stand decomposition.

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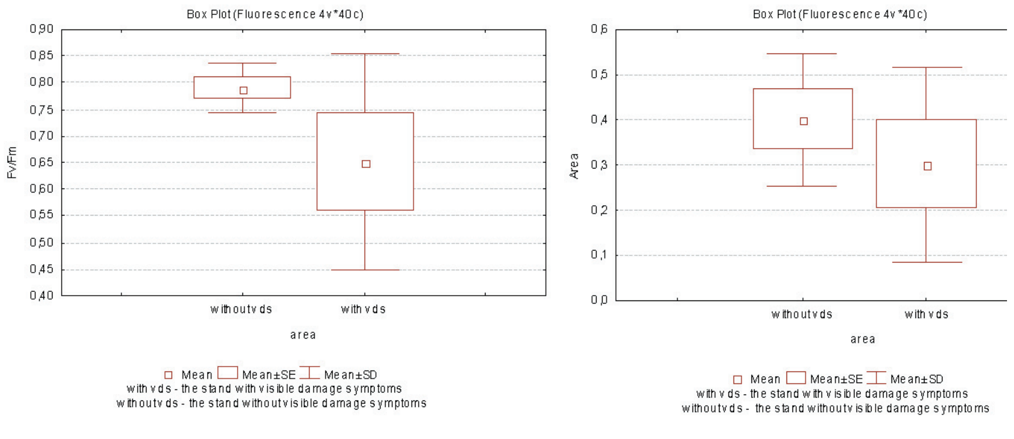

Fig 1. Course of values of parameters of chlorophyll *a* fluorescence (F_v/F_m, Area) measured on plots with different grade of stand decomposition

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Analýza fyziologických parametrov ako ukazovateľov odumierania smrečín v oblasti Horného Spiša

Súhrn

V danom príspevku je riešená problematika multifaktoriálneho odumierania smrekových porastov v oblasti Horného Spiša. Štruktúra škodlivých činiteľov v tejto oblasti je veľmi pestrá, čo sťažuje objasňovanie kauzality poškodzovania porastov.

V práci uvádzame výsledky ekofyziologického výskumu uskutočnenom v priebehu roku 2004, v rámci ktorého bol hodnotený fyziologický a následne zdravotný stav dospelých jedincov smrek. V príspevku sú zhodnotené výsledky merania parametrov fluorescencie chlorofylu *a*, koncentrácie asimilačných pigmentov (chlorofyl *a, b*, karotenoidy v mg g^{-1} sušiny) a následne vyhodnotený zdravotný stav smrekových porastov.

Výsledky získané analýzou fyziologických parametrov na úrovni dospelých jedincov smreka, svedčia o nižšej úrovni fotosyntetického procesu asimilačného aparátu u jedincov, ktoré sa nachádzali na ploche s akútnymi príznakmi rozpadu porastu, ako aj na ploche bez výrazne viditeľných príznakov rozpadu.

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Water balance of young Norway spruce and European beech mountain stands in growing seasons 2005, 2006

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Abstract

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The study evaluated all components of the water balance of a young spruce and beech stand in growing seasons 2005 and 2006 (from May 1 to October 31) at the field long-term research station Deštné in the Orlické hory Mts. Both stands lie side by side on the slope of WSW aspect at an altitude of 890 m. In 2005, the 25 years old stands were fully stocked with close canopy. Total evaporation (interception + soil evaporation + transpiration) of both stands was markedly lower in 2006 due to rainy and also rather cold growing season than in 2005, amounting to 290.1 mm in the spruce stand (367.2 mm in 2005) and only 249.6 mm in the beech stand (319.6 mm in 2005). With respect to greater evaporation of the coniferous stand in growing seasons 2005 and 2006, less water – by 32 and 36 mm (5 and 4%) percolated through the soil mantle and subsequently drained into watercourses from the coniferous spruce stand than from the broadleaved beech stand. Both stands demonstrated also high retention capacity of soil. It was documented particularly in August 2006 during intensive rainstorms (3 August – 70.1 mm; 21 August – 73.8 mm; 25 August – 64.6 mm). Water of the rainstorms was virtually fully converted into harmless subsurface runoff.

Keywords

water balance, growing season, young forest stand, Norway spruce, European beech, mountains

Introduction

In the 70s of the last century, in forestry-advanced countries of Europe, considerable attention was paid to the water-management function or hydric effectiveness of forest ecosystems (Mitscherlich, 1971; Benecke and Ploeg, 1978; Brechtel, 1976; Aussenac and Granier, 1979; Weihe, 1973; Raev, 1977; Voronkov, 1988; Item, 1981). Similar situation occurred also in the former Czechoslovakia where a number of research projects dealing the same problems were solved (Ambros, 1978; Krečmer, 1973; Peřina et al., 1973; Zelený, 1975; Tužinský, 1987). One of projects, which was dealt with by the Experiment Station Opočno was a project aimed at the study of water relations of fundamental forest tree species in mountain locations of the Czech Republic, viz spruce and beech (Kantor, 1984).

The position and importance of water-management functions of forest ecosystems were exceedingly emphasized after extreme floods in a number of European countries at the turn of the last millennium. In course of seven years, the Czech Republic was affected by three destructive floods (1997, 1998, 2002). The situation was described in a summary study entitled *Forest and Floods* (Kantor et al., 2003) published by the National Forest Committee and the CR Ministry of Environment.

Similarly also abroad, a number of papers evaluating problems of forests and water were published at that time (Gregor and Tužinský, 1999; Hammel, 2002; Škvarenina et al., 2004; Jost et al., 2005; Granier et al., 2007 etc.). Data on particular components of the water balance or on the total water regime of spruce and beech stands can be found eg in papers of Christiansen et al. (2006), Bucher-Wallin et al. (2000), Schume et al. (2003, 2005), Zirlewagen and Wilpert (2001), Tužinský (2000), Střelcová et al. (2004). It concerns data on mature stands; data on the water balance of young spruce and beech stands are, however, rather sporadic (Sonnleitner et al., 2001).

Permanent field forest research station Deštné in the Orlické hory Mts

A project mentioned in the Introduction was dealt with at the permanent field forest research station Deštné in the Orlické hory Mts. The station was established in a mature spruce and immediately neighbouring mature beech stand in 1976. Research plots are situated there on a slope of WSW aspect of 16° at an altitude of 890 m. For the period of five years, ie until 1981, all components of the water balance were studied there (interception and transpiration of tree species, evaporation from the soil surface, changes in soil moisture content, surface runoff, infiltration of water, snow cover parameters, air temperature and humidity) in mature spruce and beech stands. In winter 1981/82, both mature stands were clear-felled and planted again with spruce and beech. At the same time, measurements and study were started on all items of the water balance of newly established forest stands. In 2006, both stands were 25 years old, being in the stage of small pole (beech) or pole stand (spruce).

At present, the density of the beech stand is considerable (in 1982 at the establishment 10,000 plants ha^{-1}). Through natural mortality and one very moderate silvicultural intervention (cleaning) it has decreased to 6,490 trees ha^{-1}.

On the other hand, spruce was tended by very intensive measures already from the stage of young-growth stand (due to the danger of snowbreaks), viz from the initial density of 4,600 plants ha^{-1} in 1982 decreased to 1,180 trees ha^{-1} in 2005. Moreover, due to the precipitation-extremely above-average winter season 2005/06, spruce was totally damaged by top breaks (95% trees!!). In some cases, it were also referred stem breaks and thus in spring 2006, only 1,040 trees ha^{-1} were recorded. In addition, it is possible to suppose that the stand density will even decrease within the nearest two years due to the die-back of trees, which show only 2 to 3 living whorls at present.

Methods

Methodically, the study of the water budget in permanent balance plots in the spruce and beech stand (each of a size of 40 × 30 m) is based on the measurement and analysis of all basic items of the water balance. Interception is determined by a common method from the difference between the open area precipitation and precipitation in the stand. Throughfall is measured by a number of trough rain gauges; stem flow in the beech and spruce stands is drained from sample trees by spiral collars to intercepting barrels.

Open area precipitation is monitored in the immediate vicinity of both stands. Evapotranspiration in both stands is evaluated by the method of the continuous measurement of soil moisture across the whole soil profile. Evaporation from the soil surface and evapotranspiration of ground vegetation are measured by the set of Popov evaporimeters.

Runoff of precipitation water is assessed in 3 separate forms. Surface and hypodermic lateral runoff is measured on runoff plots 5 × 3.5 m. Vertical infiltration of water through soil is determined by lysimetric method. In three pits in the spruce stand and in three pits in the beech stand, in total 60 lysimeters are installed (in each pit 10 lysimeters). The lysimeters are placed under the level of rhizosphere, so the water retained in them can be considered to be the water available for runoff. Changes in the water content in soil are determined according to the particular horizons by sensors of volume moisture content with the automatic data assembling from 3 stabilized measuring places. Air temperature and relative humidity are continually monitored in automatic stations of Noel Co.

Results

Precipitation conditions in assessed growing seasons

In the growing season 2005, the total amount of precipitation 634.8 mm fitted within the normal limits for the given area and altitude. Precipitation was recorded in 90 days of the growing season (frequency 49%) – see Table 1, May (196.0 mm) and July (169.6 mm) were markedly above-average from the aspects of precipitation. However, the last month of the vegetation period was markedly dry (October with only 17.4 mm precipitation).

On the other hand, the precipitation in growing season 2006 was markedly above-average, namely 875.1 (see Table 2). Extreme precipitation amount was noted in August, viz 322.0 mm within 17 days. Also May (174.6 mm) and September (133.8 mm) were extraordinary from the aspect of precipitation. It is of interest that

Table 1. Open area precipitation (mm) in the permanent field research station Deštné in the growing season 2005 (Noel meteorological station) – Sa = 634.8 mm

May		June		July		August		September		October	
1. 5.	2.4	1. 6.	0.4	1. 7.	8.6	3. 8.	9.2	12. 9.	6.6	2. 10.	1.8
3. 5.	1.2	4. 6.	11.8	2. 7.	15.8	4. 8.	2.0	13. 9.	0.2	3. 10.	0.6
4. 5.	13.4	5. 6.	11.2	5. 7.	13.8	6. 8.	8.8	15. 9.	0.6	16. 10.	0.4
5. 5.	0.8	6. 6.	3.2	6. 7.	11.8	7. 8.	2.6	16. 9.	34.4	17. 10.	0.8
6. 5.	9.6	7. 6.	6.2	7. 7.	0.6	8. 8.	3.8	17. 9.	1.0	20. 10.	0.8
7. 5.	6.2	8. 6.	4.8	8. 7.	17.2	9. 8.	5.0	27. 9.	14.6	23. 10.	7.4
8. 5.	6.2	10. 6.	0.6	9. 7.	0.6	10. 8.	3.4	28. 9.	2.2	24. 10.	1.2
9. 5.	16.2	11. 6.	3.0	10. 7.	19.0	11. 8.	1.6	29. 9.	7.8	25. 10.	1.8
10. 5.	11.0	12. 6.	4.2	11. 7.	2.0	13. 8.	1.8	30. 9.	2.4	26. 10.	2.6
11. 5.	6.8	13. 6.	3.6	19. 7.	16.8	14. 8.	0.2				
15. 5.	2.8	15. 6.	3.4	20. 7.	2.4	15. 8.	7.6				
16. 5.	0.2	16. 6.	0.2	21. 7.	15.2	16. 8.	7.4				
17. 5.	18.4	18. 6.	2.0	22. 7.	14.6	17. 8.	0.2				
18. 5.	22.2	22. 6.	0.2	23. 7.	3.6	22. 8.	15.0				
23. 5.	48.6	25. 6.	4.8	25. 7.	2.0	23. 8.	22.0				
24. 5.	1.0	26. 6.	1.0	26. 7.	0.2	24. 8.	5.0				
30. 5.	25.2	30. 6.	23.8	30. 7.	14.6	25. 8.	0.2				
31. 5.	3.8			31. 7.	10.8	26. 8.	1.6				
						27. 8.	0.2				
∑ [mm]	196.0	∑ [mm]	84.4	∑ [mm]	169.6	∑ [mm]	97.6	∑ [mm]	69.8	∑ [mm]	17.4

Table 2. Open area precipitation (mm) in the Deštné station in particular precipitation days of the growing season 2006 (Noel meteorological station) – Sa = 875.1 mm

May		June		July		August		September		October	
1. 5.	30.4	4. 6.	7.2	8. 7.	1.9	1. 8.	3.7	3. 9.	34.1	1. 10.	3.7
2. 5.	1.2	5. 6.	2.1	9. 7.	23.3	2. 8.	9.2	6. 9.	2.1	2. 10.	2.2
4. 5.	16.6	9. 6.	4.1	13. 7.	2.9	3. 8.	70.1	8. 9.	30.0	3. 10.	10.1
13. 5.	23.7	10. 6.	4.1	14. 7.	1.0	4. 8.	38.7	9. 9.	1.1	4. 10.	23.5
14. 5.	11.9	17. 6.	3.1	24. 7.	11.7	7. 8.	3.7	16. 9.	3.2	9. 10.	0.4
17. 5.	30.8	20. 6.	4.6	29. 7.	35.1	11. 8.	3.7	19. 9.	62.2	24. 10.	2.6
18. 5.	10.1	21. 6.	0.5	31. 7.	2.0	12. 8.	33.2	21. 9.	1.1	25. 10.	0.7
19. 5.	3.6	22. 6.	36.0			16. 8.	1.8			27. 10.	4.1
20. 5.	9.5	28. 6.	9.8			21. 8.	73.8			28. 10.	7.1
23. 5.	1.2	29. 6.	7.7			22. 8.	5.5			29. 10.	14.9
25. 5.	7.7	30. 6.	8.2			23. 8.	3.7				
26. 5.	17.8					24. 8.	1.8				
27. 5.	1.8					25. 8.	64.6				
29. 5.	8.3					26. 8.	3.7				
						28. 8.	7.4				
						29. 8.	3.7				
						31. 8.	3.7				
∑ [mm]	174.6	∑ [mm]	87.5	∑ [mm]	77.9	∑ [mm]	332.0	∑ [mm]	133.8	∑ [mm]	69.3

the number of precipitation days was markedly lower in 2006 (in total 66, ie frequency 36%) than in the preceding year.

Water balance of spruce and beech in the growing season 2005

The water regime of the spruce and beech stand in the growing season 2005 is given in Table 3. The total amount of precipitation, viz 634.8 mm fits normal limits for the given area and altitude. Of the total amount of precipitation, 133.1 mm (21.0%) were intercepted and evaporated by crowns of spruce. As expected, interception losses of beech were lower, viz 99.4 mm (15.7%). Thus, an absolute difference between both stands was not dramatic being about 34 mm for the whole growing season.

In this connection, it is necessary to refer to significant values of stem flow in beech already in the stage of thicket or small pole stand. At intensive rainstorms (34 or 49 mm), the stem flow in dominant trees (h = 7 m; dbh = 11 cm) amounted to even 40 l water. Generally, stem flow participated very significantly in stand precipitation in the beech thicket (58.4 mm) within the whole growing season. On the other hand, stem flow in the spruce pole-stage stand was quite negligible (0.8 mm) for the whole growing season between the 1 May and the 31 October.

Unambiguously, the most important item of the water regime was evapotranspiration. It is important that similarly to the mature stands, this form of evaporation did not markedly differ even in young stands (spruce 234.1 mm, beech 220.2 mm).

Surface runoff and lateral runoff through soil were quite negligible in the two spruce and beech stands. In the precipitation above-average months May and July, the values of both forms of runoff did not exceed 0.7 or 0.6 mm (see Table 3). For the whole growing season, the surface runoff amounted to 1.9 mm (0.3%) in both stands; lateral runoff was even lower.

The part of atmospheric precipitation that was not necessary for physical and physiological evaporation of both stands infiltrated, therefore, through particular soil horizons to the subsoil. Somewhat higher infiltration in beech than spruce (318.6 mm /50.2%/ and 286.9 mm /45.2%/, respectively) can be explained by the lower interception and evapotranspiration of the broadleaved stand. An absolute difference of 31.7 mm cannot be considered to be significant from the viewpoint of total water balance or a possibility to suppress floods.

Changes in the supply of water in soil ($\pm\Delta V$ p) are the last item affecting the water regime of forest

Table 3. Water balance of spruce and of beech in the growing season from 1 May to 31 October 2005

	Open area precipitation [mm]	Stem flow [mm]	Througfall [mm]	Stand precipitation [mm]	I [m]	ET [mm]	Surface runoff [mm]	Horizontal runoff [mm]	Infiltration [mm]	± ΔVp [mm]
					Spruce stand					
May	196.0	0.2	144.9	145.1	50.9	51.3	0.4	0	92.5	+0.9
June	84.4	0.1	70.9	71.0	13.4	51.1	0.3	0	43.4	–23.8
July	169.6	0.2	135.9	136.1	33.5	43.6	0.6	0.5	79.8	+11.6
August	97.6	0.1	84.1	84.2	13.4	46.0	0.3	0.2	47.6	–9.9
September	69.8	0.2	53.1	53.3	16.5	23.3	0.3	0.1	23.6	+6.0
October	17.4	0	12.0	12.0	5.4	18.8	0	0	0	–6.8
Total	634.8	0.8	500.9	501.7	133.1	234.1	1.9	0.8	286.9	–22.0
%	100%	0.1%	78.9%	79.0%	21.0%	36.9%	0.3%	0.1%	45.2%	–3.5%
					Beech stand					
May	196.0	13.5	155.0	168.5	27.5	36.5	0.7	0.1	127.0	+4.2
June	84.4	6.9	65.9	72.8	11.6	38.3	0.3	0	44.1	– 9.9
July	169.6	18.3	120.8	139.1	30.5	54.9	0.4	0.1	75.1	+8.6
August	97.6	9.1	76.0	85.1	12.5	52.0	0.2	0	43.0	–10.1
September	69.8	9.4	47.5	56.9	12.9	22.8	0.3	0	29.4	+4.4
October	17.4	1.2	11.8	13.0	4.4	15.7	0	0	0	–2.7
Total	634.8	58.4	477.0	535.4	99.4	220.2	1.9	0.2	318.6	–5.5
%	100 %	9.2%	75.1%	84.3%	15.7%	34.7%	0.3%	0.0%	50.2%	–0.9%

ecosystems. These changes fluctuated in the course of particular months depending on the frequency of precipitation days and intensity of precipitation. Thus, at the end of the growing season, soil moisture was lower than at the beginning of May (spruce –22.0 mm, beech –5.5 mm) with respect to in precipitation markedly subnormal October.

Water balance of spruce and beech stand in the growing season 2006

The water balance of the spruce and the beech stand is given in Table 4. Primarily, it is necessary to note that in the growing season, the water regime of both stands was markedly affected by excessive precipitation – 875.1 mm in the open area. Of the total amount of precipitation, 69.3 mm (7.9% precipitation) were intercepted and evaporated by crowns of spruce trees. As expected, beech interception was lower, viz 48.3 mm (5.5% precipitation). An absolute difference between the two stands was not marked – reaching only 21.0 mm throughout the growing season.

Compared to the preceding growing season 2005, interception losses were markedly lower in both stands in summer months 2006. It can be explained by abundant horizontal precipitation particularly in May, August and October 2006 and by the marked reduction of the assimilatory apparatus after an extensive snow breakage in winter.

Also for 2006, it is necessary to stress the importance of stem flow in beech stands already in the stage of small pole stands. In the course of rainstorms in August (eg 3/8 – 70.1 mm), the stem flow amounted to even 65 litres. Generally, stem flow participated very significantly in precipitation in stands during 6 months of the growing season in the beech small pole stand (87.6 mm, ie 10.0% precipitation). On the other hand, in the spruce pole stand, stem flow represents quite insignificant item of the water regime (1.2 mm, ie 0.1% precipitation).

Thus, a decisive output item of the water regime of the spruce as well as beech stand is, as expected, evapotranspiration (ET). Similarly to the last year, it was determined by the method of continuous measurements of soil moisture across the whole soil profile.

In the development of the young spruce stand, an important change occurred in winter 2005/06. Winter storms of snow loaded spruce stands in such a way that 98% trees on the balance plot were damaged by top and stem breaks. In the studied segment of measurements of the volume soil moisture content, only one half remained from 6 spruce trees with the nearest bond to 9 VIRRIB sensors (installed at a depth of – 50, – 200, – 500 mm in three repetitions).

Table 4. Water balance of spruce and of beech in the growing season from 1/5 to 31/10/2006

	Open area precipitation [mm]	Stem flow [mm]	Throughfall [mm]	Stand precipitation [mm]	I [mm]	ET [mm]	Surface runoff [mm]	Horizontal runoff [mm]	Infiltration [mm]	± ΔVp [mm]
					Spruce stand					
May	174.6	0.2	163.4	163.6	11.0	49.0	0	0	125.8	–11.2
June	87.5	0.1	73.9	74.0	13.5	48.0	0.1	0	34.2	–8.3
July	77.9	0.1	70.7	70.8	7.1	36.9	0.5	0.1	45.4	–12.1
August	332.0	0.3	312.5	312.8	19.2	26.7	2.4	0.4	256.1	+27.2
September	133.8	0.4	118.1	118.5	15.3	46.8	1.1	0.6	79.8	–9.8
October	69.3	0.1	66.0	66.1	3.2	13.4	0.3	0	46.1	+6.3
Total	875.1	1.2	804.6	805.8	69.3	220.8	4.4	1.1	587.4	–7.9
%	100.0 %	0.1%	92.0%	92.1%	7.9%	25.2%	0.5%	0.1%	67.2%	–0.9%
					Beech stand					
May	174.6	16.8	154.8	171.6	3.0	47.1	0	0	129.8	–5.3
June	87.5	4.9	69.4	74.3	13.2	40.5	0.3	0.1	39.6	–6.2
July	77.9	2.3	71.0	73.3	4.6	33.3	0.4	0.1	49.8	–10.3
August	332.0	36.1	280.2	316.3	15.7	27.5	2.3	0.6	263.4	+22.5
September	133.8	22.9	101.3	124.2	9.6	42.9	1.2	0.1	89.8	–9.8
October	69.3	4.6	62.5	67.1	2.2	10.0	0.3	0	51.0	+5.8
Total	875.1	87.6	739.2	826.8	48.3	201.3	4.5	0.9	623.4	–3.3
%	100.0%	10.0%	84.5%	94.5%	5.5%	23.0%	0.5%	0.1%	71.2%	–0.3%

Values of evapotranspiration in particular months of the summer hydrological half-year 2006 are given in Table 4. Evaporation from the soil surface and ground vegetation transpiration evidently replaced reduction of the spruce layer transpiration. Total evapotranspiration in the spruce pole-stage stand (220.8 mm) slightly decreased compared to 2005; however, it was lower also in the beech small pole-stage stand (201.3 mm). A difference between both stands was statistically significant (p-value of the pair t-test = 0.032).

In Table 5, ET values are compared to obtain more lucidity, namely according to particular months in both growing seasons under evaluation. As compared with 2005, values of evapotranspiration in 2006 were mainly affected by the course of air temperatures, precipitation and air humidity. Lower evapotranspiration under high temperatures and low precipitation in July was caused by the low content of water in soil. On the other hand, low temperatures and the high frequency of precipitation days with markedly above-average precipitation totals caused lower evapotranspiration in August. On the contrary, favourable supply of soil water in September and above-average air temperatures resulted in rather high physiological evaporation.

Surface runoff and lateral runoff through soil were unsubstantial or even negligible both in the spruce and beech stands, similarly as in the preceding year. Even in the in precipitation extremely rich August (332.0 mm), these forms of runoff did not reach 3.0 mm (less than 1% of August precipitation). For the whole growing season, surface runoff in both stands participated in the water regime only by 0.5% precipitation and lateral runoff only by 0.1% precipitation.

An expected trend was noted in the infiltration of atmospheric precipitation through particular soil horizons to subsoil.

In consequence of markedly higher precipitation in 2006, also infiltration to the subsoil was markedly higher than in the preceding year 2005. Higher infiltration in beech, viz 623.4 mm (71.2%) compared to spruce, viz 587.4 mm (67.2%) is explainable again by lower interception and evapotranspiration of the broadleaved beech stand. However, an absolute difference (ie 36.0 mm) cannot be considered (similarly as in 2005) to be significant from the point of view of the total water balance or from the aspect of a possibility to reduce floods.

Changes in the soil water supply ($\pm\Delta Vp$) varied again in the course of particular months depending on the frequency of precipitation days and intensity of precipitation. Towards the end of growing season, soil moisture was lower than at the beginning of May (spruce –7.9 mm; beech –3.3 mm) with respect to the lack of precipitation in October.

Discussion and conclusions

Kantor (1990) summarized foreign and Czech findings on the water balance of spruce and beech stands in growing seasons up to the 90s of the last century in a summary study. According to the findings, the summary evaporation (I + E + T) ranged from 330 to 440 mm in mature spruce stands of mountain locations in the summer half-year and in mature beech stands from 305 to 390 mm. Generally higher total evaporation of coniferous stands is particularly given by the higher interception of spruce. However, evapotranspiration of both types of stands is not markedly different. It is also documented by recent papers of Tužinský (2000), Schume et al. (2003), Christiansen et al. (2006), and Jost et al. (2005).

Table 5. Evapotranspiration of a young spruce and beech stand in growing seasons 2005 and 2006 (calculations from continuous measurements of the volume soil moisture)

Evapotranspiration of a young spruce and beech stand [mm]						
Precipitation/ET	Open area precipitation		Spruce – ET		Beech – ET	
[mm]	[mm]	[mm]	[mm]		[mm]	
Month	2005	2006	2005	2006	2005	2006
May	196.0	174.6	51.3	49.0	36.5	47.1
June	84.4	87.5	51.1	48.0	38.3	40.5
July	169.6	77.9	43.6	36.9	54.9	33.3
August	97.6	332.0	46.0	26.7	52.0	27.5
September	69.8	133.8	23.3	46.8	22.8	42.9
October	17.4	69.3	18.8	13.4	15.7	10.0
Summer – total	634.8	875.1	234.1	220.8	220.2	201.3

According to Tužinský (2000), interception of spruce stands in summer months was 8% lower than in beech stands. Due to the markedly different interception process of both species, Christiansen et al. (2006) even noted marked differences in the infiltration of precipitation water under the root zone (spruce 41 mm, beech 292 mm).

Finally, interesting data can be also obtained comparing the water regime of both stands in the Deštné field research station in the calibration period 1976 to 1981 (mature stand) and in the assessed period 2005 to 2006 (young 25-year-old stand). In 1976 to 1981, at 727 mm mean precipitation over the growing season, the total evaporation (I + E + T) of the mature spruce stand amounted to 408 mm and of the mature beech stand only 305 mm (Kantor, 1990). Thus, the total evaporation of the young spruce stand was lower (290 or 367 mm) in both 2005 and 2006 but comparable with the mature spruce stand. The total evaporation of the young beech stand (250 or 320 mm) in the growing season was virtually identical with the total consumption of water of a mature beech stand.

Our fundamental findings obtained based on the analysis of the water regime of the young spruce and beech stand at the Deštné permanent field experiment station in the Orlické hory Mts in growing seasons 2005 and 2006 can be summarized as follows:

- In the precipitation – normal summer half-year 2005 (634.8 mm), crowns of spruce trees intercepted and evaporated 21.0% precipitation and crowns of beech trees 15.7% precipitation. On the other hand, at markedly above-average precipitation in 2006, viz 875.1 mm (132% normal), very low values of interception losses were noted in both stands (spruce 7.9%, beech 5.5% precipitation). In addition to the significant occurrence of horizontal precipitation this fact was in spruce very markedly affected by the disturbance of crown canopy after an extensive winter snowbreak.
- In 2006, the summary evaporation of both stands was markedly lower than in 2005 because of wet and on average also cold weather as well as by the limited supply of water in soil in the hot July (markedly lower than in 2005) amounting to 290.1 mm in spruce (in 2005 – 367.2 mm). In beech, the trend was similar, viz 249.6 mm (in 2005 – 319.6 mm). Considering the higher evaporation of the coniferous stand, about 32 mm (5%) or 36 mm (4%) less water infiltrated through soil and then drained to watercourses in spruce than in the broadleaved beech stand in both years.
- From the viewpoint of possibility to reduce floods, the high retention potential of forest soils has been proved in both compared stands even during rainstorms – 23/5/2005 (48.6 mm), 3/8/2006, or 21/8/2006 (73.8 mm), which infiltrated to subsoil. Surface runoff was quite negligible (in both stands maximally 0.5% total precipitation). This fact can be considered to be the most important finding from both evaluated seasons.

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Vodní režim mladého horského smrkového a bukového porostu ve vegetačních obdobích 2005 a 2006

Souhrn

Stěžejní poznatky z analýzy vodního režimu mladého smrkového a bukového porostu na stacionáru Deštné v Orlických horách ve vegetačních obdobích 2005 a 2006 lze shrnout do tří následujících bodů:

Ve srážkově normálním letním půlroce 2005 (634,8 mm) se zadrželo a vypařilo z korun smrků 21,0 % srážek, z korun buků 15,7 % srážek. Naproti tomu při výrazně nadprůměrných srážkách v roce 2006 – 875,1 mm (132 % normálu) byly v obou porostech zaznamenány velmi nízké hodnoty intercepčních ztrát (smrk 7,9 %, buk 5,5 % srážek). Vedle významného výskytu horizontálních srážek byla ve smrku tato skutečnost velmi výrazně ovlivněna i narušením zápoje korun po rozsáhlém zimním sněhovém polomu.

V roce 2006 byl sumární výpar obou porostů v důsledku vlhkého a v průměru i chladného počasí, ale i omezené nabídky vody v půdě v horkém červenci, výrazně nižší než v roce 2005 a činil ve smrku 290,1 mm (v roce 2005 – 367,2 mm). V buku byl tento trend obdobný – 249,6 mm (v roce 2005 – 319,6 mm). S ohledem na vyšší výpar jehličnatého porostu prosáklo půdou a následně odteklo do vodotečí ve smrku, v obou letech o cca 32 mm (5 %), resp. 36 mm (4 %) vody méně než v listnatém bukovém porostu.

Z pohledu možností tlumení velkých vod byla potvrzena vysoká retenční schopnost lesních půd v obou srovnávaných porostech i při přívalových srážkách – 23. 5. 2005 (48,6 mm), 3. 8. 2006, resp. 21. 8. 2006 (73,8 mm), které v celém rozsahu prosákly půdou na podloží. Povrchový odtok byl zcela zanedbatelný (v obou porostech maximálně 0,5 % celkových srážek). Tuto skutečnost lze považovat za nejvýznamnější poznatek z obou hodnocených období.

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Atmospheric deposition and critical loads in a climax oak forest in the Štiavnické vrchy Mts

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Abstract

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Air pollutants have been for decades subjected to scientific research – due to their worldwide impact on the people's health and natural environment. We sampled vertical precipitation in an oak forest ecosystem at the locality Skalie in the Štiavnické vrchy Mts. The obtained samples partially represent the atmospheric deposition – the process of accumulation of air pollutants on the ground surface. These samples were evaluated from the viewpoint of acid rain. In accordance with the assumption, there have been found apparent differences in annual concentrations of chemical components and elements between the rain water having passed through tree crowns (throughfall) or forest edges and the open area. The sulphates ranged from 3.8 in the open area to 18.2 mg l^{-1} in the forest gap. In case of nitrogen, the values of atmospheric deposition ranged from 13.8 kg ha^{-1} yr^{-1} in the forest gap to 23 kg ha^{-1} yr^{-1} under the oak crowns, in case of sulphur we obtained 7.7 in the open area and 23.8 kg ha^{-1} yr^{-1} in the forest gap. Comparing the calculated deposition loads with the critical loads, we did not observe exceeding of limits.

Key words

oak forest ecosystem, acid precipitation, atmospheric deposition, critical loads, the Štiavnické vrchy Mts

Introduction

Forest ecosystems still belong to the most endangered parts of the natural environment. One of the main threats is input of air pollutants. Determining sources of air pollution are: power engineering, including energetic equipments of industrial plants and local heating, industrial technologies, especially metallurgy, chemistry, production of building materials and quickly developing road transport. Unfavourable effects of air pollution across the major part of Slovakia are multiplied by its remarkably broken topography. A number of big industrial plants are situated in deep valleys and hollow basins with restricted conditions for dispersal of pollutants in the atmosphere. In closer surroundings of these pollutant sources, ultimate ecological and environmental damage is observed permanently. Apart from this, the whole central Europe is still an area with strong regional air pollution and acid precipitation resulting mainly from transboundary transport of air pollutants (Posch et al., 2005).

From the above-said it is apparent that the damage can not only be done to forests in neighbourhood of industrial or residential areas but also to forests relatively remote from these pollution sources. This was also the case of our research plot influenced by a relatively remote source – the aluminium plant in Žiar nad Hronom. The amounts of substances emitted from the plant do not represent a significant share in total balance of air pollution and in consecutive damage to forest ecosystems in Slovakia. On the other hand, the quality and aggressiveness of these pollutants cause considerable weakening, or even destruction, of forest ecosystems in the area of the pollutants´ impact. At last, in our case we can speak about a peculiar aluminium air pollution mode. Our point of interest is acidifying air pollution. For a long time, thousands tons of SO_2 were leaving the aluminium plant, and their spreading area was rather large – due to a 204 m high chimney (Kellerová, 2005).

The impact of air pollution on forest ecosystems can be manifested in different forms. Subsequent processes running in soils are often key important in studying the problem. They can manifest themselves through degradation of soil organisms' microbial activity (eg Gömöryová and Střelcová, 2006). Therefore, we need to evaluate all these processes and to recognise the "buffering capability"of forest ecosystems in relation to these substances (Kunca et al., 2006).

Acid rain and the connected processes of deposition of miscellaneous components on the ground surface maintain a topical problem, because the global climate change and greenhouse effect are increasing in popularity. Research on contaminant input from air and precipitation quality in different types of forest ecosystems in Slovakia can be dated since long. However, we have to underline that this research has almost always been focused on uplands or mountain areas where this process is quantitatively more pronounced (eg Minďáš and Kunca, 1997; Kellerová, 2006). There were also performed some similar measurements in oak forests, to certain extent (eg Tužinský, 2004), but we have no information on any performed in the Štiavnické vrchy Mts. With this paper we would like to contribute to the knowledge database of atmospheric deposition and acid rain in Slovakia but also to information on the oak throughfall. This is also important for hypothesising about a potential climate change in forest ecosystems.

The objective of our work was to determine the annual values of precipitation quantity and quality in the studied oak ecosystem (*Quercus petraea* (Matt.) Liebl.) and to compare them with the values from the adjacent open area. Based on these measurements, we quantify atmospheric deposition fluxes and confront them with the calculated values of critical deposition loads. In general, we evaluate impact of precipitation, mainly from view of its quality, on total hydrochemical balance of oak forest ecosystems.

Material and methods

At three sampling spots at the permanent research plot (PRP) – open (control) area, forest gap and under crown space – all the types of vertical precipitation, partially also horizontal precipitation intercepted in trees crowns, were collected in three polyethylene rain gauges (with a capture area of 475 cm^2) and evaluated as bulk deposition. The samples were taken regularly at 10 to 14 day intervals, and always when necessary. The chemical analyses were primarily focused on acidifying (also potentially for soil) chemical substances as sulphates, nitrates and ammonium. In terms of basic biochemical balance, we also determined principal base cations, electric conductivity and pH values in the samples. The value of electric conductivity (EC) expresses the bulk concentration of all chemical substances (mineralization) in water solution.

The bulk annual deposition is the sum of deposed amounts of components determined in precipitation (NH_4^+, NO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+) over a year. It is given in kg ha^{-1} yr^{-1}. Deposition of each compound was calculated as the product of the compound's concentration in mg l^{-1} detected in the precipitation sample and the precipitation quantity fallen on a unit area in mm, and afterwards summarised for the observed period (year) (Fea, 1996). All the average values were calculated as weighted means.

The samples were processed in the laboratory of the Technical University in Zvolen, Faculty of Forestry, Department of Natural Environment. The description of methods used in the laboratory analyses can be found in Mihálik et al. (1993).

The PRP Skalie is situated in territory of the School Forests in Kysihýbeľ near Banská Štiavnica. The PRP was established towards the end of 2004, with the purpose of monitoring fluxes and atmospheric precipitation quality in a natural forest ecosystem with prevailing sessile oak. The stand is two-storied and classified as a protective forest, aged from 180 to 190 years, with a stand density of 0.7. The PRP is localised at an altitude of 680 m asl, on a SW oriented slope. The soil type is cambisol. The species composition of the forest is following: sessile oak 80%, European beech 10%, hornbeam 5% and allochtonous Norway spruce 5%.

Results and discussion

Maximum precipitation totals were found, in accordance with expectations, in the open area where the annual total was 597 mm. Minimum values, which represented only 65% of the open area values, were found in the forest gap. Here the long crowns of several trees bordering the gap have probably a significant influence on interception and evaporation. The annual throughfall total was found 472 mm. Comparing the data obtained for the throughfall with the corresponding values found in the open area, significant differences in concentrations of chemical compounds and elements in throughfall and edge-effect-influenced precipitation in the examined oak forest ecosystem are apparent (Table 1). It is especially evident in case of electric conductivity. The values of this parameter, increasing from the open area via the forest gap to the under-crown space, confirm a high enrichment of precipitation. There was also found similar growing trend for the other compounds with exception of sulphates.

Table 1. pH values, electric conductivity (EC in µS cm^{-1}) and average concentrations of chosen chemical substances in mg l^{-1} in precipitation on permanent research plot Skalie

	pH	EC	NH_4^+	NO_3^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K+
Open area	6.1	23.4	3.3	1.0	3.8	0.7	0.2	0.6	1.5
Forest gap	5.9	37.5	4.2	1.0	18.2	1.1	0.3	0.7	7.5
Throughfall	5.9	46.1	5.8	1.6	11.9	2.2	0.5	0.9	9.4

In general, the critical range of precipitation acidity has been established as H^+ concentrations exceeding 0.3 mg l^{-1} or pH values less or equal to 3.5; to which correspond sulphates concentrations above 14 mg l^{-1} (Škvarenina, 1997). The comparison of the threshold values with our values listed in Table 1 shows that the pH values are significantly below the critical limit and they are relatively low also in Slovak conditions with slightly acid chemical reaction. However, sulphates surprisingly exceeded the limit in the space of forest gap where some specific processes like small turbulences of the air masses and larger contacting area of longer tree crowns can play a role.

In connection with these parameters, we give a list of the total input of these substances from atmosphere. In Table 2 are evident certain differences in particular chemical components dependent on localisation of the sampling spot. Typical are the values from the forest gap where the well-known "edge effect" of tree crowns is apparent. The total input of nitrogen (anion and cation form) ranges between 13.8 kg ha^{-1} yr^{-1} in the forest gap and 23 kg ha^{-1} yr^{-1} under the oak crowns. For sulphur, this interval is from 7.7 to 23.8 kg ha^{-1} yr^{-1} but inversely ordered – from the open area to the forest gap.

For comparison we also present the results of Kunca (2005) who has determined the model values of atmospheric deposition with acidifying potential in the territory of the Štiavnické vrchy Mts for three altitudinal levels (Table 3). The biggest differences between the modelled and measured values can be observed for nitrogen, especially for its ammonium form. It seems that a hypothesised slowly growing trend of this precipitation component in Slovakia has turned to reality. On the other hand, the nitrate deposition is quite low, which is probably caused by a long distance of the plot from the main transport communications.

Comparison of our deposition values with the critical loads gives us information about possible negative impact of atmospheric components entering the forest ecosystem. Kunca (2005) sets for the oak forest ecosystems in the Štiavnické vrchy Mts critical values of sulphur deposition loads ranging from 0.2 to 16.4 keq ha^{-1} yr^{-1} with the average value of 2 keq ha^{-1} yr^{-1}. After conversion of our deposition results according to the specific natural conditions of the examined oak forest, when the highest input of sulphur was found in the forest gap (23.8 kg S ha^{-1} yr^{-1} = 1.5 keq S ha^{-1} yr^{-1}), it is obvious that at the PRP Skalie the critical limits for acidifying sulphur have not been exceeded.

The same we can conclude about the critical loads of nitrogen in the Štiavnické vrchy Mts where they range from 0.7 to 33 keq ha^{-1} yr^{-1} with the average value of 3.1 keq ha^{-1} yr^{-1}. The highest input of both forms of nitrogen is in the under-crown space (23 kg N ha^{-1}

Table 2. Values of atmospheric deposition in kg ha^{-1} yr^{-1} for oak forest ecosystem and open area on permanent research plot Skalie

	$S\text{-}SO_4^{2-}$	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$	Ca^{2+}	Mg^{2+}	Na^+	K^+
Open area	7.7	1.3	15.1	4.2	1.1	3.7	9.1
Forest gap	23.8	0.9	12.9	4.5	1.3	2.9	29.4
Throughfall	18.7	1.7	21.3	10.5	2.5	4.2	44.1

Table 3. Model values of acidifying components from atmospheric deposition for three altitudinal levels in open area and oak forest ecosystem in territory of the Štiavnické vrchy Mts in kg ha^{-1} yr^{-1} (Kunca, 2005)

Altitude	$S\text{-}SO_4^{2-}$		$N\text{-}NO_3^-$		$N\text{-}NH_4^+$	
	Open area	Oak stand	Open area	Oak stand	Open area	Oak stand
300 m	8.5	14.4	3.7	4.4	7.2	8.6
550 m	11.7	19.9	4.3	5.2	8.5	10.2
1000 m	13.7	23.2	5.1	6.1	10.0	11.9

yr^{-1} = 1.6 keq S ha^{-1} yr^{-1}). Comparing the values we can see that the critical limits have not been exceeded either in this case.

Compared to the critical acid loads in the Slovak forest ecosystems, especially oak, (Minďáš et al., 1999) it is apparent that the 95 percentile critical limit for sulphur – 22.5 keq ha^{-1} yr^{-1} has not been exceeded.

Conclusions

From viewpoint of water balance in the studied oak forest ecosystem, the lowest values were determined in the forest gap, and they only represented 65% of the amount found in open area (597 mm). Significant change in concentrations of chemical compounds and elements in the rain water having passed through crowns or through forest edges in the oak forest ecosystem is apparent from our further results and comparisons with the open area. Mainly from viewpoint of quality, we have revealed some notable facts which can significantly influence the total hydro-chemical balance of oak forests. In spite of certain abatement of air pollution in Slovakia, the share of some xenobiotic substances in precipitation is kept rather high – concentration of sulphates in the forest gap is higher than the limit of 14 mg l^{-1}. The total input of nitrogen ranges from 13.8 kg ha^{-1} yr^{-1} in the forest gap to 23 kg ha^{-1} yr^{-1} in the throughfall. The interval of atmospheric deposition of sulphur is from 7.7 to 23.8 kg ha^{-1} yr^{-1} with the minimum values occurring in the open area to the maximum ones in the forest gap. The values of acid load measured on the research plot Skalie have not exceeded the critical limits.

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Atmosférická depozícia a kritické záťaže klimaxovej dubiny v Štiavnických vrchoch

Súhrn

Z pohľadu vodnej bilancie dubového lesného ekosystému sme najnižšie hodnoty, ktoré predstavovali len 65 % z hodnôt voľnej plochy (597 mm), zistili v porastovej medzere. Z našich ďalších výsledkov a porovnaní s voľnou plochou je zrejmá výrazná zmena koncentrácií chemických zložiek a elementov po prechode korunami alebo ich okrajom v dubovom lesnom ekosystéme. V týchto prírodných podmienkach je význam atmosférických zrážok, ich kvality a kvantity, zrejmý. Hlavne z pohľadu ich kvality sme zistili niektoré zaujímavé fakty, ktoré môžu výrazne ovplyvniť celkovú hydrochemickú bilanciu dubových lesných ekosystémov – podiel niektorých xenobiotických látok v zrážkach je stále, aj po určitom celoslovenskom znížení hlavne emisií síry, pomerne vysoký (koncentrácia síranov v porastovej medzere je väčšia ako limitných 14 mg l^{-1}). Celkový vstup dusíka (obidve formy) sa pohybuje zhruba od 13,8 kg ha^{-1} rok^{-1} v porastovej medzere po 23 kg ha^{-1} rok^{-1} pod korunou duba. V prípade síry je to od 7,7 po 23,8 kg ha^{-1} rok^{-1} od voľnej plochy po porastovú medzeru. V prípade výskumnej plochy Skalie však nedochádza k prekračovaniu kritických záťaží acidity pre síru a ani dusík.

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Flight activity of beetles (Coleoptera) in Vysoké Tatry Mts (Malaise fauna)

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Abstract

Majzlan, O. 2008. Flight activity of beetles (Coleoptera) in Vysoké Tatry Mts (Malaise fauna). *Folia oecol.*, 35: 20–29.

In 2006 we studied flight activity of beetles at 4 sites in Vysoké Tatry Mts using a method of Malaise traps. The research was focused to find differences in diversity and equitability of beetle coenoses in 2 biotope types. The assemblages appear balanced in undamaged forest habitats. At deforested sites we recorded decline in equitability.

Key words

beetle assemblages, ecology, diversity

Introduction

2 years after the wind disaster (November 19, 2004) in Vysoké Tatry Mts we analysed flight activity of beetles in 2 types of habitats. The new situation has formed "a nature laboratory" including its new ecological conditions. A cold air mass, a bora, with a speed of 170 km per hour had disaster effects on forest complexes, which have suddenly changed into open habitats. Consequentially this has been followed by increased radiation and new proportion in atmospheric gas concentration (oxygen and carbon dioxide). The assimilation potential of forests has declined what has been temporarily accompanied by an increase of decomposition components. The destroyed forest has followed significant natural succession of vegetation. However the development of coenoses, particularly entomocoenoses are less visible and requires more complex methods to be studied. According to our experiences Malaise traps are one of them.

Study area

4 research sites were established on southern slopes of Vysoké Tatry Mts from Tatranská Lomnica to Vyšné Hágy. 2 traps were installed, one of them in Tatranská Lomnica (Štart) in a forest site (Fig 1) and the second one in the National Nature Reserve Studené doliny – Jamy (deforested site). The traps were exposed since May 4, 2006 (exposition period of 148 days).

The second couple of traps were installed at the site of Nová Polianka – Danielov dom (deforested site, Fig 2) and Vyšné Hágy – Smrekovec (a forest site). These traps were exposed since May 15, 2006 (exposition period of 137 days).

Fig 1. The Malaise trap in Larici-Piceetum at the site of Tatranská Lomnica – Štart (photo by O. Majzlan, May 16, 2006)

Fig 2. The Malaise trap at the deforested site in Nová Polianka – Danielov dom (photo by O. Majzlan, May 16, 2006)

In terms of phytosociology the vegetation at all the sites can be classified as Larici-Piceetum.

Material and methods

A Malaise trap is the sampling equipment, which analyses flight activity of arthropods, especially insects. It works permanently and without attractants. The material was collected in regular weekly intervals. The traps were installed from May 19 to September 30, 2006 (total exposition period of 134 days).

Diversity and equitability were evaluated using the Simpson´s indices.

The material was analysed by various experts and compared with relevant research in Slovakia (Majzlan, 2002).

Results

Research on flight activity of insects, especially beetles (Coleoptera) enhances to evaluate character of biotopes after the wind disaster. From 4 Malaise traps 222 beetle species were obtained (Table 1). Based on the quality and quantity, as well as on the chosen ecological variables, the sites may be ordered:

Species richness: Štart (111) – Jamy (110) – Danielov dom (86) – Smrekovec (74)

Quantity: Danielov dom (517) – Štart (495) – Jamy (422) – Smrekovec (319)

Diversity: Štart (63) – Jamy (50) – Smrekovec – (52) Danielov dom (23)

Equitability: Smrekovec (0.69 – Štart (057) – Jamy (0.45) – Danielov dom (0.27).

The site Smrekovec shows stable and balanced values of equitability in beetle communities suggesting a climax stage of the locality (original forest phytocoenoses Abieti-Piceetum). The community includes only 2 dominant species: *Polydrusus impar* (15.6%) and *Athous subfuscus* (7.8%).

The higher quantity (517 ex) refers to the site of Danielov dom (Daniel´s house); however the equitability reaches its minimum (0.27). The community contains 6 dominant species: *Athous subfuscus* (15.8%), *Polydrusus impar* (9.8%), *Podabrus alpinus* (7.4%), *Rhagonycha translucida* (6.8%), *Coccinella septempunctata* (6.0%), *Rhagonycha atra* (5.2%) which decrease qualitative – quantitative balance in the community as they form 51% of all the specimens.

Deforested sites are characterised by lower values of equitability reflecting the disturbed function of the forest. The other sites are in various stage of succession. Beetle communities seem to be more diverse (higher diversity) and balanced (equitability) in climax stages.

Table 1. A survey of the beetle species recorded from the Malaise trap at 4 sites in 2006 (including a month of collection an their abundance)

Family	Štart	Jamy	Danielov dom	Smrekovec
Species				
Carabidae				
Bradycellus csikii Laczó, 1812	5/1			
Calathus micropterus (Duftschmid, 1812)				8/1
Dromius agilis (Fabricius, 1787)		6/1, 7/1	7/1, 8/1	
Dromius fenestratus (Fabricius, 1794)	5/1, 6/1, 7/1, 8/2		8/4, 9/3, 10/1	
Notiophilus biguttatus (Fabricius, 1779)		6/1	8/1, 9/1	7/1
Trechus quadristriatus (Schrank, 1781)	5/1			
Dytiscidae				
Agabus guttatus (Paykull, 1798)	9/1			

Table 1. Continued

Family	Štart	Jamy	Danielov dom	Smrekovec
Species				
Silphidae				
Necrophorus vespilloides Herbst, 1784	7/1			7/1
Necrophorus sepultor Charpentier, 1825	7/1			
Leiodidae				
Anisotoma castanea (Herbst, 1792)	7/1			
Anisotoma humeralis (Fabricius, 1792)				6/1, 8/1
Catops coracinus Kellner, 1846		7/1		
Catops nigriclavis Gerhardt, 1900	9/1		9/1	
Catops nigrita Erichson, 1837	9/1		7/1	5/1, 7/1
Catops subfuscus Kellner, 1846	8/1			
Catops tristis (Panzer, 1794)	10/2			7/1, 8/15, 9/6, 10/2
Choleva cisteloides (Frölich, 1799)	10/2	6/1		8/1
Choleva nivalis (Kraatz, 1856)	9/1			
Choleva sturmi Brisout, 1863	10/1			
Leiodes ferruginea (Fabricius, 1787)				8/2
Leiodes oblonga (Erichson, 1845)			8/1	
Sciodrepoides watsoni (Spence, 1815)	7/1, 8/1			5/1, 7/2
Staphylinidae				
Aleochara sparsa Heer, 1839				10/2
Aleochara stichai Likovský, 1965	8/2			8/2
Amphichroum canaliculatum (Erichson, 1840)		6/1		
Atheta laticollis (Kirby, 1832)			10/1	
Atheta picipes (Thomson, 1856)	8/1			
Atheta trinotata (Kraatz, 1856)	8/1			
Broyphacis rufus (Erichson, 1792)				9/1
Drusilla canaliculata (Fabricius, 1787)			10/1	
Leptusa pulchella (Mannerheim, 1830)	8/1			8/1
Lordithon lunulatus (Linnaeus, 1860)	8/3			8/2
Ontholestes tesselatus (Fourcroy, 1758)		5/1		
Philonthus addendus Sharp, 1867		9/1		
Philonthus cognatus Stephens, 1832		9/5	10/1	
Philonthus marginatus (Stroem, 1768)				10/1
Philonthus succicola Thomson, 1855				9/2
Phloeostiba plana (Paykull, 1792)				8/2
Phyllodrepa floralis (Paykull, 1789)		9/1		
Quedius mesomelinus (Marsham, 1802)	8/1	9/3	10/6	8/3, 9/3, 10/14
Quedius nitipennis (Stephnes, 1833)	9/2		10/10	10/1
Quedius paradisianus (Heer, 1839)		9/2		8/3
Tachinus pallipes (Gravenhorst, 1806)				10/1
Tachinus proximus Kraatz, 1855	8/2			8/8, 9/2
Clambidae				
Calyptomerus alpestris Redtenbacher, 1849				8/1

Table 1. Continued

Family	Štart	Jamy	Danielov dom	Smrekovec
Species				
Helodidae				
Cyphon rufipes Tournier, 1868		6/16, 9/7		
Cyphon variabilis (Thunberg, 1787)		5/2, 6/1, 9/5	7/1	
Elodes pseudominuta Klausnitzer, 1971		6/1		
Scarabaeidae				
Aphodius fimetarius (Linnaeus, 1758)				8/1
Phyllopertha horticola (Linnaeus, 1758)	6/1	7/4	6/1	
Buprestidae				
Anthaxia quadripunctata (Linnaeus, 1758)		6/1		
Elateridae				
Ampedus aethiops (Lacordaire, 1835)	6/1			
Ampedus auripes (Reitter, 1895)			5/1	7/1
Ampedus nigrinus (Herbst, 1784)		6/1		6/2
Athous subfuscus (Müller, 1767)	6/9, 7/32	6/39, 7/28	6/15, 7/82	6/25, 7/4
Ctenicera cuprea (Fabricius, 1781)	6/25, 7/1	6/2		
Dalopius marginatus (Linnaeus, 1758)	6/3, 7/2	6/9	5/6, 6/3	6/1
Denticollis interpositus Roubal, 1841			7/1	
Denticollis rubens (Pill. et. Mitt., 1783)		6/1		7/1
Kibunea minuta (Linnaeus, 1758)	6/1,7/1			
Melanotus castanipes (Paykull, 1800)		6/1	7/1	
Prosternon tesselatum (Linnaeus, 1758)			7/1	
Selatosomus aeneus (Linnaeus, 1758)	6/2	5/1,6/1	5/4, 6/2	
Homalisidae				
Omalisus fontisbellaquei (Geoffroy, 1762)			7/4	
Lycidae				
Dictyoptera aurora (Herbst, 1784)		7/1	7/1	7/3
Platycis minutus (Fabricius, 1787)			8/3	7/2, 8/1, 9/1, 10/1
Lampyridae				
Lampyris noctiluca (Linnaeus, 1767)				7/2
Phosphaenus hemipterus (Geoffroy, 1762)	6/1			
Drilidae				
Drilus concolor Ahrens, 1812	5/1	5/2		6/1
Cantharidae				
Cantharis fulvicollis Fabricius, 1792		5/1	7/1	7/1
Cantharis obscura Linnaeus, 1758			7/2	
Cantharis pagana Rosenhauer, 1846		6/5	6/5	
Cantharis pellucida Fabricius, 1792	6/1		7/1	
Cratosilis denticollis (Schummel, 1844)	7/4, 8/1	7/2	7/12	7/6
Malthinus biguttatus (Paykull, 1800)	7/1	6/4	8/1	5/1, 6/1
Malthinus flaveolus (Herbst, 1786)	7/1	8/2	8/2	7/1, 8/5
Malthinus seriepunctatus Kiesenwetter, 1851	6/4, 7/10		5/1	6/2
Malthodes brevicollis (Paykull, 1798)	5/5		6/2	
Malthodes hexacanthus Kiesenwetter, 1852	6/1, 7/2		6/1	7/4, 8/5
Podabrus alpinus (Paykull, 1798)	7/1, 8/6	6/4, 7/4	7/38	6/1, 7/1

Table 1. Continued

Family	Štart	Jamy	Danielov dom	Smrekovec
Species				
Rhagonycha atra (Linnaeus, 1767)	7/4, 8/1	7/1	7/27	7/4, 8/1
Rhagonycha elongata (Fallén, 1807)	7/11	8/1	7/4	7/1
Rhagonycha testacea (Linnaeus, 1758)	7/3, 8/5	7/1	7/1	
Rhagonycha translucida (Krynicky, 1832)	7/15, 8/2	7/6	7/35	7/13
Anobiidae				
Caenocara bovistae (Hoffmann, 1803)			8/1	
Ernobius abietis (Fabricius, 1792)	6/1	5/1, 7/1	10/2	
Ernobius nigrinus (Sturm, 1837)		6/3		
Trogositidae				
Nemozoma elongatum (Linnaeus, 1761)		6/1		
Cleridae				
Thanasimus formicarius (Linnaeus, 1758)		6/5, 7/3	6/1, 10/1	
Thanasimus pectoralis (Zetterstedt, 1828)	6/1			
Dasytidae				
Aplocnemus tarsalis (Sahlberg, 1822)			5/5, 7/2	
Malachiidae				
Charopus graminicola (Dejean, 1833)	6/1	7/1		
Lymexylonidae				
Hylecoetus dermestoides (Linnaeus, 1761)	7/1			
Nitidulidae				
Carpophilus mutilatus Erichson, 1843		7/1		
Cychramus variegatus (Herbst, 1792)	8/1, 9/1			10/2, 9/5
Epuraea angustula Sturm, 1844		7/1		
Epuraea marseuli Reitter, 1872	6/1			6/1, 7/1
Epuraea neglecta (Heer, 1841)	8/1			
Epuraea unicolor (Olivier, 1790)				7/1
Meligethes aeneus (Fabricius, 1775)	7/1, 9/1	6/1		
Meligethes viridescens (Fabricius, 1787)	7/2, 8/5, 9/1	6/1	7/1	8/5, 9/1
Thalycra fervida (Olivier, 1790)			6/1	
Rhizophagidae				
Rhizophagus depressus (Fabricius, 1792)			10/1	
Sphindidae				
Aspidiophorus orbicularis (Gyllenhal, 1808)	8/1			
Cucujidae				
Placonotus testaceus (Fabricius, 1787)		7/1		
Cryptophagidae				
Henoticus serratus (Gyllenhal, 1808)		9/1		
Byturidae				
Byturus tomentosus (De Geer, 1774)		6/3		
Erotylidae				
Triplax lepida Faldermann, 1835	6/1			
Endomychidae				
Mycetina cruciata (Schaller, 1783)			5/1	

Table 1. Continued

Family *Species*	Štart	Jamy	Danielov dom	Smrekovec
Coccinellidae				
Anatis ocellata (Linnaeus, 1758)	8/12, 9/1			
Aphidecta obliterata (Linnaeus, 1758)	9/2	6/2		5/1
Ceratomegilla alpina redt. (Capra, 1928)			7/1	
Coccinella septempunctata Linnaeus, 1758	6/1, 7/21, 8/15, 9/3	5/2, 7/11, 8/1	5/2, 7/31, 8/12,9 3,10/2	
Halyzia sedecimguttata (Linnaeus, 1758)	7/1	6/1,7/3		
Hippodamia tredecimpunctata (L., 1758)			7/1, 10/1	
Myzia oblongopunctata (Linnaeus, 1758)	8/1			
Propylea quatuordecimpunctata (L., 1758)	8/2, 9/1	6/1, 7/1	5/1, 7/5, 8/2	
Scymnus abietis Paykull, 1798				7/1
Lathridiidae				
Aridius nodifer (Westwood, 1839)	8/1, 9/1		9/1	
Cartodere constricta (Gyllenhal, 1827)				
Corticaria ferruginea Marsham, 1802			7/1	
Corticaria rubripes Mannerheim, 1844	8/1, 9/3			
Corticarina fuscula (Gyllenhal, 1827)		7/4		
Cortinicara gibbosa (Herbst, 1793)		9/1		
Enicmus fungicola Thomson, 1868				
Enicmus histrio Joy et Tomlin, 1910				7/1
Latridius minutus (Linnaeus, 1767)		9/1		
Stephostethus rugicollis (Olivier, 1790)	6/1			
Ciidae				
Cis punctulatus Gyllenhal, 1827			7/1	
Melandryidae				
Xylita livida (Sahlberg, 1834)		6/1		
Xylita laevigata (Hellenius, 1786)		5/1		
Mordellidae				
Mordella aculeata (Linnaeus, 1758)		5/1	6/1	
Mordella brachyura Mulsant, 1856				
Mordellistena brevicauda (Boheman, 1849)	5/1, 7/4			
Mordellistena dieckmanni Ermisch, 1963	6/1			
Mordellistena kraatzi Emery, 1876		8/4		7/1
Mordellistena micantoides Ermisch, 1954	6/3, 7/5			
Mordellistena neuwaldeggiana (Panzer, 1796)				6/2
Mordellistena pumila (Gyllenhal, 1810)				5/1
Mordellistenula perrisi (Mulsant, 1856)			6/1, 7/2	8/4
Mordellochroa abdominalis (Fabricius, 1775)	5/1, 7/1		6/1	
Tomoxia bucephala Costa, 1854	6/1			
Variimorda basalis (Costa, 1854)	5/1	6/1		6/4
Scraptidae				
Anaspis arctica Zetterstedt, 1828	5/1, 8/8			6/5
Anaspis frontalis (Linnaeus, 1758)	6/1		5/2	7/2
Anaspis ruficollis (Fabricius, 1792)			5/5	
Anaspis rufilabris (Gyllenhal, 1827)		6/2		6/10, 7/5

Table 1. Continued

Family	Štart	Jamy	Danielov dom	Smrekovec
Species				
Salpingidae				
Rabocerus gabrieli (Gerhardt, 1901)		6/1		
Salpingus ruficollis (Linnaeus, 1761)	8/1			
Lagriidae				
Lagria hirta (Linnaeus, 1758)		7/1, 8/1	7/2	
Cerambycidae				
Acanthoderes clavipes (Schrank, 1781)		7/1		
Acmaeops septentrionis (Thomson, 1866)	6/2, 7/2	7/1		
Allosterna tabacicolor (De Geer, 1775)	8/1			
Anastrangalia dubia (Scopoli, 1763)		7/3	6/1	7/1
Carilia virginea (Linnaeus, 1758)		6/1, 7/4	7/2	
Cortodera femorata (Fabricius, 1787)			5/1, 6/2	
Evodinus clathratus (Fabricus, 1792)	5/6, 6/15	5/5, 6/1		
Grammoptera ruficornis (Fabricius, 1781)			7/1	
Isarthron castaneum (Linnaeus, 1758)	6/3, 7/2	6/3	6/6	
Isarthron fuscum (Fabricius, 1787)	6/1		5/1	
Molorchus minor (Linnaeus, 1758)		7/1		
Monochamus sutor (Linnaeus, 1758)		8/1		
Obrium brunneum (Fabricius, 1792)	8/2		6/1	
Oxymirus cursor (Linnaeus, 1758)		5/1, 6/2	5/12, 6/3	
Pachyta lamed (Linnaeus1758),		7/2	6/1	
Pachyta quadrimaculata (Linnaeus, 1758)		6/1, 7/4		
Pachytodes cerambyciformis (Sch., 1781)		7/1	7/1	
Pidonia lurida (Fabricius, 1792)	7/1	5/12, 6/1, 7/3	6/3, 7/1	7/1
Pogonocherus fasciculatus (De Geer, 1775)	6/1	5/1, 6/1, 9/3		
Pseudovadonia livida (Fabricius, 1776)	7/1			
Rhagium inquisitor (Linnaeus, 1758)				
Rhagium mordax (De Geer, 1775)		7/1		
Stenurella melanura (Linnaeus, 1758)		7/1	7/1	7/1
Chrysomelidae				
Altica quercetorum Foudras, 1859		7/1		5/1
Cryptocephalus labiatus (Linnaeus, 1761)				8/1
Cryptocephalus ocellatus Drapiez, 1819	7/1		6/3	
Gonioctena viminalis (Linnaeus, 1758)	7/1			
Chaetocnema concinna (Marsham, 1802)		7/1		
Chrysolina hyperici (Forster, 1771)	9/1			
Chrysolina varians (Schaller, 1783)	7/1			
Longitarsus lateripunctatus Weise, 1893		7/1		
Longitarsus melanocephalus (De Geer, 1775)	8/2			
Longitarsus scutellaris (Rey, 1847)		9/1		
Luperus viridipennis (Germar, 1824)	7/14, 8/45, 9/3, 10/1	8/8		7/7
Oulema gallaeciana (Heyden, 1870)	5/1, 7/1	6/1, 9/1		
Phyllotreta exclamationis (Thunberg, 1784)	7/1			
Phyllotreta nemorum (Linnaeus, 1758)	8/1	5/1		

Table 1. Continued

Family	Štart	Jamy	Danielov dom	Smrekovec
Species				
Chrysomelidae				
Phyllotreta nigripes (Fabricius, 1775)	5/1			
Anthribidae				
Brachytarsus nebulosus (Forster, 1771)	6/3, 7/1	5/2, 6/13, 7/3	6/3, 7/3	6/1, 7/1
Attelabidae				
Caenorhinus germanicus (Herbst, 1797)	6/1			
Cimberis attelaboides (Fabricius, 1787)	8/2	5/2, 6/2	5/1	
Curculionidae				
Anthonomus phyllocola (Herbst, 1795)		5/1		
Anthonomus pinivorax Silfverberg, 1977	8/1			
Brachonyx pineti (Paykull, 1792)		5/1		
Cionus scrophulariae (Linnaeus, 1758)			7/1	
Curculio glandium Marsham, 1802		7/1		
Ellescus bipunctatus (Linnaeus, 1758)			5/1	
Gymnetron tetrum (Fabricius, 1801)		6/1		
Hylobius abietis (Linnaeus, 1758)		6/1	8/1	
Magdalis linearis (Gyllenhal, 1827)		6/1		
Magdalis nitida (Gyllenhal, 1827)		7/1		
Magdalis phlegmatica (Herbst, 1797)		6/1		
Magdalis punctulata (Mulsant et Rey, 1859)	9/1			
Magdalis violacea (Linnaeus, 1758)			7/1	
Miarus graminis (Gyllenhal, 1813)			7/1	
Otiorhynchus lepidopterus (Fabricius, 1794)		7/2	5/3	5/1
Otiorhynchus niger (Fabricius, 1775)		6/1, 7/1		
Otiorhynchus scaber (Linnaeus, 1758)	8/3, 9/1			
Phyllobius alpinus Stierlin, 1859				7/1
Phyllobius arborator (Herbst, 1797)				6/1, 7/1
Phyllobius calcaratus (Fabricius, 1792)				7/1
Pissodes castaneus (De Geer, 1775)		5/1,9/1		
Pissodes harcyniae (Herbst, 1795)		7/2, 8/2, 9/7		
Pissodes piceae (Illiger, 1807)		5/1, 7/4	6/1, 7/1	
Pissodes scabricollis Miller, 1859		8/1, 9/1		
Polydrusus cervinus (Linnaeus, 1758)				7/1
Polydrusus impar Des Gozis, 1882	9/1	6/4, 7/3	6/22, 7/28	5/1, 7/50, 8/2
Polydrusus pilosus Gredler, 1866		5/1		6/2
Sitona hispidulus (Fabricius, 1776)	9/1			
Sitona inops Gyllenhal, 1832	9/2			
Sitona lineatus (Linnaeus, 1758)			9/2	
Sitona macularis (Marsham, 1902)	9/1			
Sitona sulcifrons (Thunberg, 1798)	8/1	6/2		
Strophosoma melanogrammum (Forster, 1771)	9/2			
Scolytidae				
Dendroctonus micans (Kugelann, 1794)	6/6, 7/3			
Hylastes cunicularius Erichson, 1836		6/1		

Table 1. Continued

Family	Štart	Jamy	Danielov dom	Smrekovec
Species				
Ips typographus (Linnaeus, 1758)	5/4, 6/14, 7/3, 9/2	5/8, 6/11, 7/9, 8/19	5/3, 6/3	8/10
Pityophthorus exsculptus (Ratzeburg, 1837)	7/1			
Pityophthorus glabratus Eichhoff, 1878		9/1		
Polygraphus poligraphus (Linnaeus, 1758)		7/1		
Tomicus piniperda (Linnaeus, 1758)	10/1			
Xyloterus lineatus (Olivier, 1795)		7/1		

In initial stages they contain more zoophagous species, oligo- and polyphagous phytophagous elements as well as numerous invasive, infiltrating and accidental species. Succession towards climax gradually eliminates several species from the community. Finally the coenosis reaches stability on the level of its eucenous species and finds balance amongst its phytophagous and zoophagous elements. Therefore we may evaluate the sites of Jamy, Danielov dom and Štart as changed and developing in their first initial stage.

The flight activity of beetles had the following daily means:
Štart 3.7 ex/day, Jamy 3.1 ex/day, Danielov dom 3.8 ex/day and Smrekovec 2.4 ex/day. These values are comparable with data from other localities in Slovakia (Majzlan, 2002).

The flight activity shows its maximum in June and July (Fig 3) including the absolute peak of 220 specimens at the site of Danielov dom in July (7.1 specimens per day in average). Such a value is typical for hills rather than for submontane and montane regions. Abundance of beetles studied during vegetation season culminates in July and August at all the sites (Table 2).

Amongst the recorded species we can determine several stenoecious and faunistically important elements.

Choleva nivalis, Choleva cisteloides and *Choleva sturmi* (Leiodidae) live in burrows of micromammals, which were probably overpopulated at open sites after deforestation (site Jamy).

Calyptomerus alpestris inhabits old decaying spruces and common silver fir. Mountainous element, which was even found in burrows of *Marmota marmota* (Roubal, 1930). In Slovakia very rare. Found at the site Smrekovec (August 14, 2006, 1 ex).

Denticollis interpositus, montane species, described from Slovakia, in the whole area rare and local.

Ampedus nigrinus and *Ampedus auripes*, montane species indicating natural habitats. Found particularly at the site Smrekovec.

Henoticus serratus, submontane and montane species, inhabiting naturally diverse environment. In Slovakia local and rare.

Enicmus fungicola, Stephostethus rugicollis, Corticaria ferruginea and *Corticaria rubripes*. These lathridids indicate stable biotopes. In Slovakia rare.

Pachyta lamed, a montane species being classified as a pest of spruce wood (together with *Pachyta quadrimaculata*). It intensively attacks fresh wood in mountains. In Slovakia local and rare.

Cimebris attelaboides, the European species (the area extends to Asia Minor). It inhabits pines where it feeds on their buds. In Slovakia known from Moravian region to Tatry Mts.

Anthonomus phyllocola and *Anthonomus pinivorax*, weevils living on flowering spruces and pines. Exclusively montane species, locally occuring at higher altitudes in Slovakia.

Pissodes harcyniae and *Pissodes castaneus* as well as the other species of the genus Pissodes are considered as pests of coniferous species, especially of their young plants. These two species are however rare and local in Slovakia.

Table 2. Abundance of beetles in the Malaise trap (monthly at a site)

Site	May	June	July	August	September	October	Total
Štart	30	118	167	136	37	7	495
Jamy	53	161	126	40	42	–	422
Danielov dom	63	85	220	111	11	27	517
Smrekovec	8	60	128	78	21	24	319

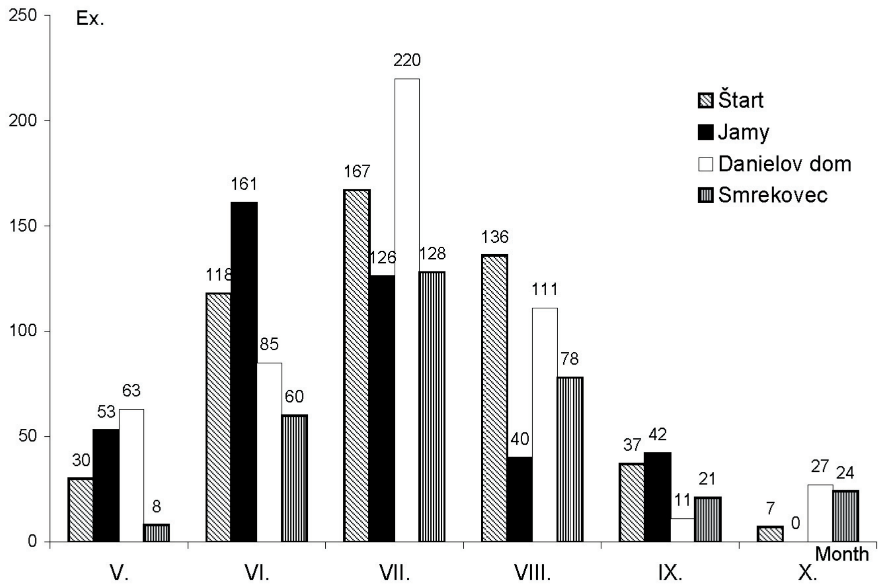

Fig 3. Dynamics of beetle quantity in the study period in 2006 at 4 sites in Vysoké Tatry Mts

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Letová aktivita chrobákov (Coleoptera) vo Vysokých Tatrách (Malaise fauna)

Súhrn

V roku 2006 sme metódou Malaiseho pascí študovali letovú aktivitu chrobákov. Na 4 plochách vo Vysokých Tatrách sme na základe získaného študijného materiálu stanovili diverzitu a ekvitabilitu cenóz chrobákov. Porovnávali sme dva typy plôch. Lesné spoločenstvo jedľo-smrečín a dve plochy po kalamite. Vyrovnané cenózy boli v lesných typoch. Na kalamitných plochách dochádza k rýchlej sukcesii cenóz chrobákov. Ekvitabilita je posunutá v prospech viacerých dominantov.

Celkove sme zistili 222 druhov chrobákov. Priemerná letová aktivita bola 3,2 ex./deň.

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Throughfall chemistry and atmospheric deposition in a Norway spruce – subalpine climax forest in the Poľana Biosphere reserve, Slovakia

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Abstract

Mihaliková, K., Škvarenina, J., Střelcová, K., Gömöryová, E. 2008. Throughfall chemistry and atmospheric deposition in a Norway spruce – subalpine climax forestry in the Poľana Biosphere reserve, Slovakia. *Folia oecol*., 35: 30–39.

This work deals with chemistry of precipitation and atmospheric deposition in a climax spruce stand in the Poľana Mts. Vertical precipitation and throughfall was sampled on the research plot Predná Poľana in years 2004–2006. Precipitation was collected from two plots − a spruce forest stand and open area. The purpose of our work was to interpret the chemical-physical characteristics of vertical precipitation (pH, electric conductivity), to determine concentrations of selected chemical substances (SO_4^{2-}, NO_3^-, K^+, Na^+, Mg^{2+}, Ca^{2+}, NH_4^+) and to evaluate the wet atmospheric depositions of main elements (H^+, S, N and alkaline elements). We observed increasing precipitation acidity and significant pollution more enriching stand precipitation than the open area. The pH values in throughfall ranged from 3.43 to 6.09, in lysimetric waters from 3.29 to 5.86 and in open area from 4.9 to 6.42. The results show an increase in pH values, and decrease in all the followed elements and substances in both concentration and deposition, both on the open plot and in the stand.

Key words

vertical precipitation, throughfall, chemistry of precipitation, atmospheric deposition, acidification

Introduction

The human activities at the millennium change are influencing, intentionally or unintentionally, the entire living environment on the Earth. The vigorous development in areas of industry, agriculture, car and air transport and changes to landscape have entailed progressive disturbances to equilibrium of the natural environment. Very negative impact is owing to air pollution that does not take in consideration any borders. The attributes of airborne pollutants are: wide range of chemical transformations, dispersion, distribution and transboundary transport. Apart from the precipitation water, the forests and other ecosystems are also entered by many other in-the-air-present chemical elements and substances that cause and accelerate acidification of the natural environment (Fišák et al., 2006). Over the past years, atmospheric emissions in Central Europe decreased considerably (Matschullat et al., 2000), however, the impact of anthropogenic pollutants on forest ecosystems is still a hot topical problem. The Slovak Republic is situated in Central Europe, on the boundary of the territory with the heaviest regional air pollution on the continent. The level of regional pollution influences the load to most forest plots in Slovakia, and it requires, consequently, a special attention. The transboundary transport of pollutants represents, under the prevailing zonal airflow, about 60%. The harmful impact has not avoided our biggest volcanic mountain massive Poľana, too (Kunca, 2003). The natural environment of the PLA – BR has been, already since the 60-s, a spot for natural environment study, especially for workers from the University in Zvolen (Sláviková, 1993). A special attention should be paid to the work Mihálik and Slávik (1988), focussing on polluted precipitation in the area of the Poľana massive, already in the 80-s of the last century. Since 1991, the load with airborne pollutants has been being studied by workers from the Forest Research Institute and from the Faculty of Forestry of the Technical University in Zvolen who established the comprehensive research-demonstration subject Poľana – Hukavský Grúň. In 2002, there was started monitoring of wet atmospheric deposition at the research locality Predná Poľana, situated in a mountain ridge spruce forest at 1347 m asl. The data obtained for this locality are subjected to closer examination in this work.

Methods

The experiment was realised on a research site Predná Poľana which is localised in the southwestern part of Biosphere Reserve Poľana. The main characteristics of the research plot are shown in the Table 1.

The material from the research plot was sampled in vegetation periods 2004–2006, once or two times a month. The sampling periods were the following: in year 2004 from 24.6. to 10.11., in year 2005 from 16.6. to 15.11., and in year 2006 from 30.5 to 30.11. The vertical precipitation and precipitation in the stand (throughfall) was collected into polyethylene collectors each with a catching area of 200 cm^2, made from material chemically inert to precipitation water. The lysimetric water was collected into plate lysimeters made from stainless steel, with catching area of 500 cm^2. The type of precipitation sampler and lysimeter was the same.

The precipitation was sampled from five collectors and four lysimeters. The open plot was provided with one collector situated in the young growth, one in the age-differentiated group, one in the stand gap, and one under an old spruce tree, the last one together with the lysimeter. The lysimeters were installed under the humus horizon, at a depth of 30 cm. In our work we use the following abbreviations for the sampling spots (Table 2).

In the text, the abbreviations are appended with symbols 04, 05, 06, expressing the sampling year. Chemical laboratory analysis was carried out in a common way, following the methods listed in Table 3, (Mihálik et al., 1992).

From the data sets of results of chemical analysis we have calculated the values of the following statistic variables (Šmelko, 1998): arithmetic mean, weighed arithmetic mean, median, modus, standard deviation, variation coefficient, percentiles (10%, 25%, 75%, 90%). Apart from these variables, we also examined the maximum and minimum value of the sampling set and precipitation totals. To calculate the atmospheric deposition, the precipitation total over the vegetation period was converted to the annual total. Statistical significance of differences between arithmetic means obtained for individual plots was tested using variance analysis, Duncan test.

Table 1. Characteristic of the research plot Predná Poľana

Altitude [m]	Exposition	Tree composition [%]	Mean annual temperature	Mean precipitation total	Soil type
1347	SW	spruce 93 beech 4 mountain ash 3	3.5–4.0 °C	900–1000 mm	andosols cambisols

Table 2. Abbreviations of the individual sampling spots

Sampling spot	Abbreviation
Open plot	PV
Precipitation gauge in the young growth	PZ1
Precipitation gauge in the age-differentiated group of trees	PZ2
Precipitation gauge in the stand gap	PZ3
Precipitation gauge under the old spruce tree	PZ4
Lysimeter in the young growth	PL1
Lysimeter in the age-differentiated tree group	PL2
Lysimeter in the stand gap	PL3
Lysimeter under the old spruce tree	PL4

Table 3. Methods used in chemical analysis for determining concentrations of individual components in the samples

Parameter	Method	Unit
pH	Potentiometer. with a high-resistance electrode	
Conductivity	Conductometry	µS cm^{-1}
SO_4^{2-}	Nitration with lead nitrate on indicator ditizon in acetone environment	mg l^{-1}
NO_3^-	Calorimetry. with sodium salycil. in sulphuric acid environment	mg l^{-1}
K^+	Atomic absorption spectrophotometry	mg l^{-1}
Na^+	Atomic absorption spectrophotometry	mg l^{-1}
Mg^{2+}	Atomic absorption spectrophotometry	mg l^{-1}
Ca^{2+}	Atomic absorption spectrophotometry	mg l^{-1}
NH_4^+	Colometry. using Nessler agent	mg l^{-1}

Results and discussion

Values of pH, electric conductivity

Graphical interpretation of the statistic characteristics of pH values is in Fig 1. The range of weighted means is from 3.45 (PL1 04) to 5.57 (PV 05). The highest acidity was found for throughfall (4.27) and lysimetric water (3.86) in the young growth (PZ1). The lowest precipitation acidity was on the open plot (5.57). Progressing over the study period 2004–2006, there were observed increasing pH values, then followed a drop in 2006 almost on the all plots. Lysimetric waters were more acid than the corresponding throughfall. Comparison between pH values of precipitation on open plot and of throughfall, using the variance analysis and Duncan test, revealed statistically very significant differences (significance level $\alpha < 0.01$) between PV and all the other plots, with exception of PZ4, where the difference was only significant (significance level $\alpha < 0.05$).

Electric conductivity (EC) of a solution is a measure of the total amount of ions in the solution. On the research plot Predná Poľana, the highest values were observed for the lysimeters, followed by the throughfall and open plot. The weighed means of EC for the period 2004–2006 were: on the open plot (PV) 18.48 µS cm^{-1}, in the throughfall 16.46–37.79 µS cm^{-1}, in lysimetric waters 41.7–68.44 µS cm^{-1}.

Concentration of sulphates, nitrates, nitrogen – ammonium cation and basic cations

The lowest mean SO_4^{2-}, NO_3^- and NH_4^+ concentrations were measured on open plot. Soil solution was more concentrated than the corresponding throughfall. The young growth (PZ1) characterizes the highest concentration of observed chemical substances. For the entire study period 2004–2005 we can see decrease in concentrations.

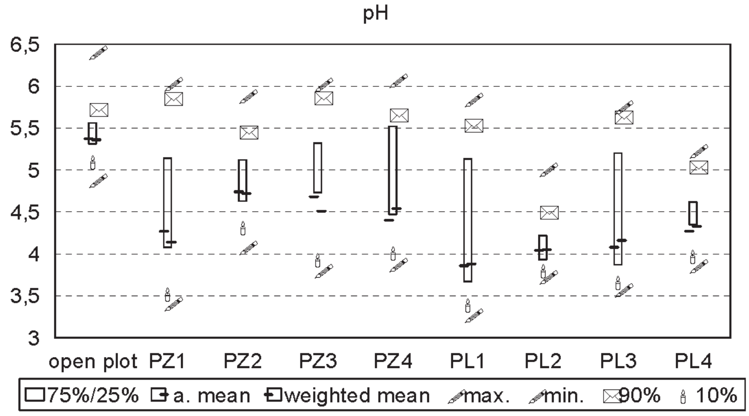

Fig 1. Statistical interpretation of pH values in the period 2004–2006

The mean values in the throughfall ranged from 4.41(PZ2) to 8.32 mg l^{-1} (PZ1), in lysimetric water from 6.15 (PL2) to 13.43 mg l^{-1} (PL1). The lowest mean SO_4^{2-} concentration 4.68 mg l^{-1} was found on open plot. The absolute maximum, 75.2 mg l^{-1}, was measured on plot PL4 in 2006, the minimum 0.8 mg l^{-1} on plot PZ3 in 2004. In Fig 2 is evident that the lysimeters at the individual sampling sites copy the course of throughfall, their values, however, are shifted upwards. The results of Duncan test confirmed significant differences in arithmetic means only in case of open plot and the lysimeter situated in the young growth (PL1).

Graphical evaluation of NO_3^- values is in Fig 3, NH_4^+ concentrations are in Fig 4. Absolute measured maximum, 63.25 mg l^{-1}, was recorded on plot PL4 06, minimum 0.2 mg l^{-1} on plot PZ2 05. The mean NO_3^- concentration on open plot was 2.52 mg l^{-1}. The mean value in the throughfall ranged between 1.55 (PZ3)–4.57 (PZ4) mg l^{-1}, in the lysimetric water from 8.05 (PL3) to 13.81 mg l^{-1} (PL1), what is 3.7–6-times more than in the throughfall. The trend of concentration values in individual years is very unbalanced, we can however agree on a decrease up to 2006 on most plots. The most conspicuous was this decrease in lysimetric water.

The highest concentrations of the second form of nitrogen – ammonium cation NH_4 were found in lysimeters ranging from 2.42 to 3.77 mg l^{-1} with the maximum on plot PL2. The weighed means of the throughfall moved from 1.2 to 2.38 mg l^{-1}, with the biggest weighed mean reached on plot PZ1. We observed the lowest mean NH_4^+ concentration 1.08 mg l^{-1} on the open plot. The same hierarchy: open plot – stand – lysimeters can also be observed in the separate years, the trends, however, are specific for different sampling sites.

The results of variance analysis point out, however, a difference, statistically very significant (significance level $\alpha < 0.01$), in NO_3^- concentrations between

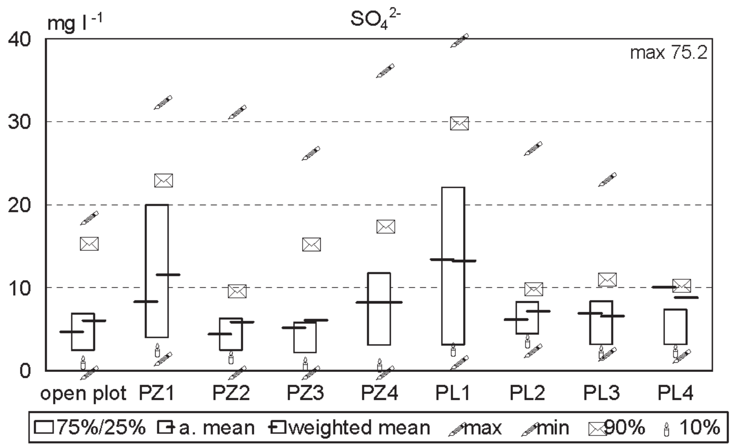

Fig 2. Graphical interpretation of SO_4^{2-} concentrations in 2004–2006

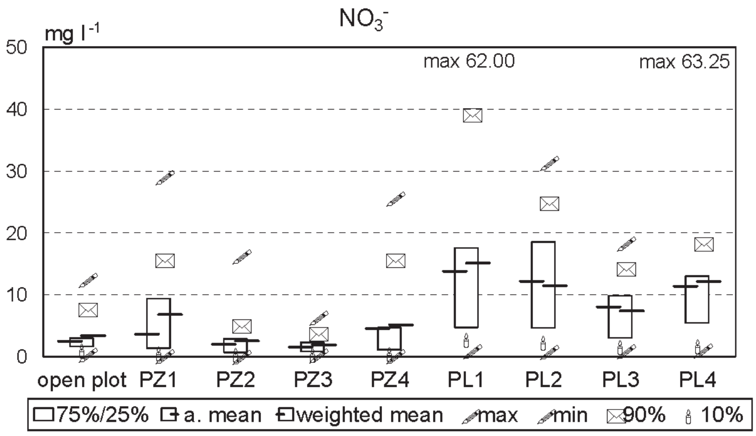

Fig 3. Graphical interpretation of statistic values of NO_3^- in 2004–2006

open plot and plots PL2 , PL3; in case of NH_4^+, there were significant differences between plots PV and PZ1, PZ2, PZ3.

Comparing our results with the results other authors (Table 4), we can see they are comparable. It is evident decrease in pH values and reduction in SO_4^{2-}, NO_3^-, NH_4^+ concentrations in the recent years.

For all the studied alkaline elements is in general true that their concentrations increased both in the lysimetric water and in throughfall, unlike the precipitation on the open plot. The alkaline elements content was most enhanced in the soil solutions. Examining the values of these cations on the research plot Predná Poľana, we can see that the most abundant elements on the open plot were Ca^{2+} (0.77 mg l^{-1}) and Na^+ (0.51 mg l^{-1}), in the throughfall it was K^+ and Ca^{2+}. The conspicuous increase in K^+ and Ca^{2+} concentrations in the throughfall suggests that the origin of these elements is in the biomass leaching K^+ and Ca^{2+} cations intensively after having had contact with acid precipitation. The increase in concentrations of K^+ and Ca^{2+} is evident, beginning with the open plot towards the plots with developing canopy. An increase in K^+ and Ca^{2+} concentrations in throughfall opposite to open area has also been documented by Minďáš and Kunca (1997), who observed calcium concentrations 1.1–1.9-times higher after having passed spruce crows, in case of magnesium the original value increased by 6.5–10.9-times. Pavlenda (2007) reports for Poľana in year 2005 values of calcium on open plot 0.85 mg l^{-1}, in the stand 1.03 mg l^{-1}, concentration potassium in the stand 1.93 mg l^{-1}, on open plot 0.2 mg l^{-1}.

The mean magnesium concentrations were lower than concentrations of other alkaline elements. The lowest increase was observed on the open plot 0.51 mg l^{-1}. Also in this case is well observable increase in mean concentration with increasing stand canopy.

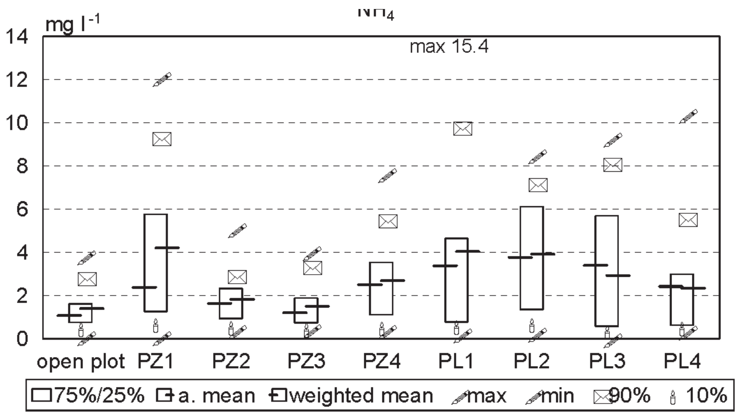

Fig 4. Graphical interpretation of statistic values NH_4^+ in 2004–2006

Table 4. Comparison of selected characteristics according to various authors

Locality		Altitude [m]	pH	SO_4^{2-} [mg l^{-1}]	NO_3^- [mg l^{-1}]	NH_4^+ [mg l^{-1}]	Authors Measured period
Predná Poľana	op ss	1347	5.37 4.27–4.73	4.68 4.34–8.32	2.52 1.55–4.57	1.08 1.20–2.50	This work (2007) 2004–2006
Poľana – Hukavský Grúň	op ss	850	4.58 4.67	1.92 3.05	2.26 3.89	0.44 0.92	Pavlenda (2007) 2005
Zadná Poľana	op ss	1430	4.88–5.66 3.75–5.24	5.33–17.31 5.24–31.18	1.56–3.59 1.56–4.59	1.10–3.29 1.74–4.53	Bublinec and Dubová (2000) 1991–1997
Poľana – Hukavský Grúň	op ss	850	4.64 –	3.90 13.81	2.01 4.99	1.32 3.32	Minďáš and Kunca (1997) 1996
Predná Poľana	op ss	1320	– –	7.36 53.29	2.07 8.31	1.36 7.13	Mihálik and Slávik (1988) 1986

op – open plot, ss – spruce forest

The mean sodium concentrations in the throughfall ranged from 0.64 (PZ3) to 0.95 mg l^{-1} (PZ4), in lysimetric water from 0.73 (PL2) to 1.0 mg l^{-1} (PL1), the weighed mean on the open plot was 0.51 mg l^{-1}.

Duncan test confirmed a difference, statistically high significant, in Ca^{2+} and Mg^{2+} concentrations for plots PZ1, PL1, PL4 compared with the open one. The difference PV – PL2 in concentrations of both elements was significant at a level $\alpha < 0.05$. In case of potassium, the difference between PV and the other plots was found very significant, with plot PZ3 significant. Very significant differences were identified in concentrations Na^+ between the open plot and plots PZ1, PZ4, PL1 and PL4.

Deposition of sulphur, total nitrogen, H^+ and basic cations

On the research plot were found the considerable values sulphur, total nitrogen and the hydrogen ion deposition. The lowest deposition input was recorded on the open plot. The deposition in lysimeters in all the followed elements was lower than in the stand, in spite of the fact that the concentrations were showing an opposite trend.

Graphical representation of sulphur deposition at the individual sampling sites is in Fig 5. For the entire study period 2004–2006 is possible to observe increase in sulphur deposition. In the given time sulphur deposition ranged between 6.66–33.12 kg ha^{-1} year^{-1} (except for maximum), in the stand, from 2.04 to 17.11 kg ha^{-1} year^{-1} in the lysimeters and reached 12.03–23.11 kg ha^{-1} year^{-1} on the open plot. Conspicuous increase was on sampling spot under the old spruce (PZ4), on which deposition reached its maximum (51.74 kg ha^{-1} year^{-1}). This is the result of the highest precipitation total and, at the same time, concentration on plot PZ4 compared to the preceding years.

The final values of total nitrogen deposition in 2004–2006 are illustrated in Fig 6. The trend of total nitrogen deposition is very unbalanced for different sampling sites. Both in open plot and in the stand it doesn't cross value 30 kg ha^{-1} year^{-1}, except for plot PZ4, when the deposition input in year 2006 reached 60.55 kg ha^{-1} year^{-1}. Similar to other elements, the nitrogen depositions in lysimeters were lower than in the forest stand.

We compare our measured values of sulphur and nitrogen deposition with results other authors, which deal with this theme over the Poľana orographic area. Table 5 refers about individual differences found on open plot and in spruce stand.

The mean annual values of H^+ deposition in 2004 ranged from 0.07 to 1.23 kg ha^{-1} year^{-1}. In 2005 was observed a notable, more than 50% reduction in H^+ deposition on all the plots except for PZ4 and PL4, where the deposition input was higher. In 2006 there followed a moderate increase again, from 0.02 to 0.12 kg ha^{-1} year^{-1} on most plots. Pavlenda (2007) reports for open plot in Poľana H^+ deposition 0.08 kg ha^{-1} year^{-1} in 2004, 0.02 kg ha^{-1} year^{-1} in 2005. Our results are higher, but the deposition in 2005 is comparable (0.03 kg ha^{-1} year^{-1}).

The input of base cations in throughfall deposition results from two different sources, total deposition (wet + dry + interception), and internal leaching. The latter is the dominating mechanism for K^+. The leaching efficiency depends on ambient SO^{2-}concentrations (Slovik et al., 1996) and on precipitation, because K^+ is highly mobile and present as an electrolyte within the plant. The SO^{2-} decrease consequently led to a reduction of K^+

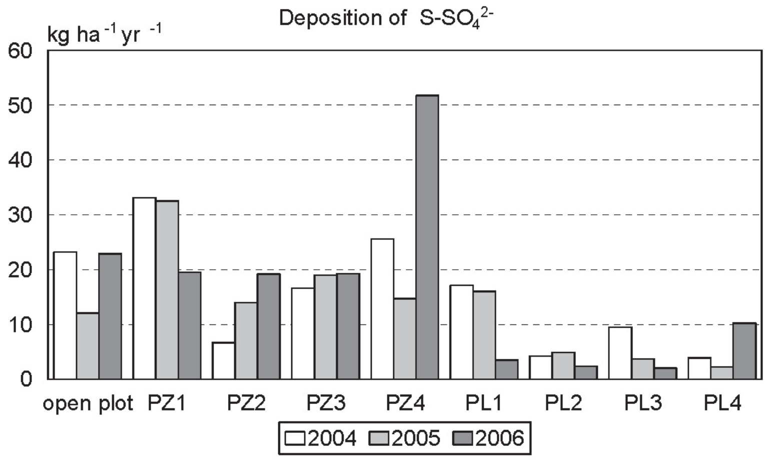

Fig 5. Graphical interpretation of elementary sulphur deposition

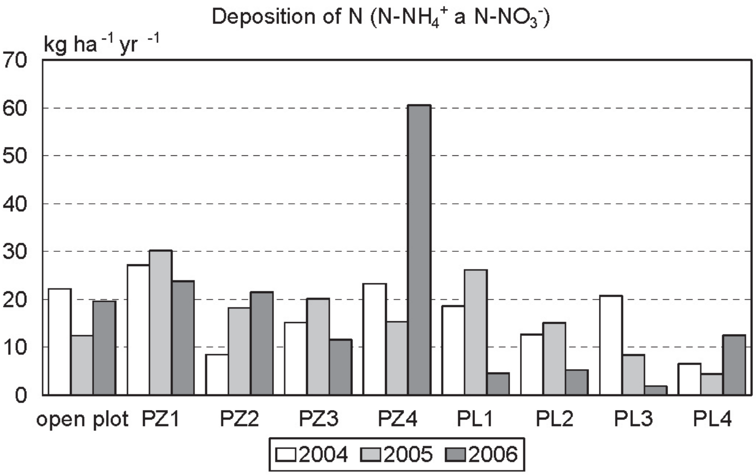

Fig 6. Graphical interpretation of total nitrogen deposition

Table 5. Comparison of S and N deposition according to various authors in area Poľana

Locality		Altitude [m]	S	N	Authors Measured period
Predná Poľana	op	1347	19.38	18.07	This work (2007)
	ss		13.27–30.66	15.61–33.04	2004–2006
Poľana – Hukavský Grúň	op	850	5.70	7.46	Pavlenda et al. (2007)
	ss		7.52	10.99	2005
Zadná Poľana	op	1430	39.00	15.20	Bublinec and Dubová (2000)
	ss		78.00	33.40	1996–1997
Poľana – Hukavský Grúň	op	850	15.00	14.30	Minďáš (1999)
	ss		26.80	23.10	(1993–1997)
Predná Poľana	op	1320	20.20	11.70	Mihálik and Slávik (19918)
	ss		99.00	40.70	(1986–1987)

op – open plot, ss – spruce forest

input. Observed variations were simply related to precipitation variability. Different from K^+, both Ca^{2+} and Mg^{2+} are bound to plant tissue and are being exchanged via ion exchange processes against protons. Lower pH-values thus lead to higher leaching rates. Thus, the reduction of Ca^{2+} and Mg^{2+} deposition is not only related to a reduction in dust emissions but to the increase of pH-values in precipitation (Zimmerman et al., 2003).

Graphical interpretation of the values of wet deposition of basic cations in the period 2004–2006 is in Fig 7 (a–c), highest deposition inputs over the study period were observed, in accord with the concentration values, also for potassium and calcium. Their depositions are highest in forest stand. The deposition input of calcium on open plot represented 7.25–13.51 kg ha^{-1} year^{-1}, in forest stand it ranged from 4.19 (PZ2) to 42.63 kg ha^{-1} year^{-1} (PZ1), in lysimeters from 1.55 (PL2) to 8.27 kg ha^{-1} year^{-1} (PL4).

Considerably conspicuous differences in potassium deposition could be observed between the open plot and forest stand. The deposition on open plot was moderately increasing, starting with a value of 1.48 in year 2004 up to 3.84 kg ha^{-1} year^{-1} in year 2006. The potassium input on open plot was the lowest among all the studied basic cations. The trend of potassium deposition in lysimeters was decreasing, except for plot PL4. Blihárová and Škvarenina (1999) for locality Predná Poľana in year 1999 give deposition of calcium 15.1 ha^{-1} year^{-1} in stand, for K^+ 15.1 ha^{-1} year^{-1}.

Deposition of magnesium is most conspicuous below the stand. On the open plot, the values in study period ranged from 1.43–2.89 kg ha^{-1} year^{-1}, the values in lysimeters were showing a slightly decreasing trend (except for PL4 – a steep increase in 2006). The values of sodium deposition on open plot and in forest stand are more equalized than in case of the other alkaline elements. The deposition input of sodium on the open plot was the highest one among all the basic cations. For all the studied elements, lysimeters were showing lower deposition values compared to forest stand.

MINĎÁŠ and TÓTHOVÁ (2004) suggest that assessment and interpretation of basic elements deposition should be carried out with a bit of care, especially in the stand, because the values measured in stand precipitation

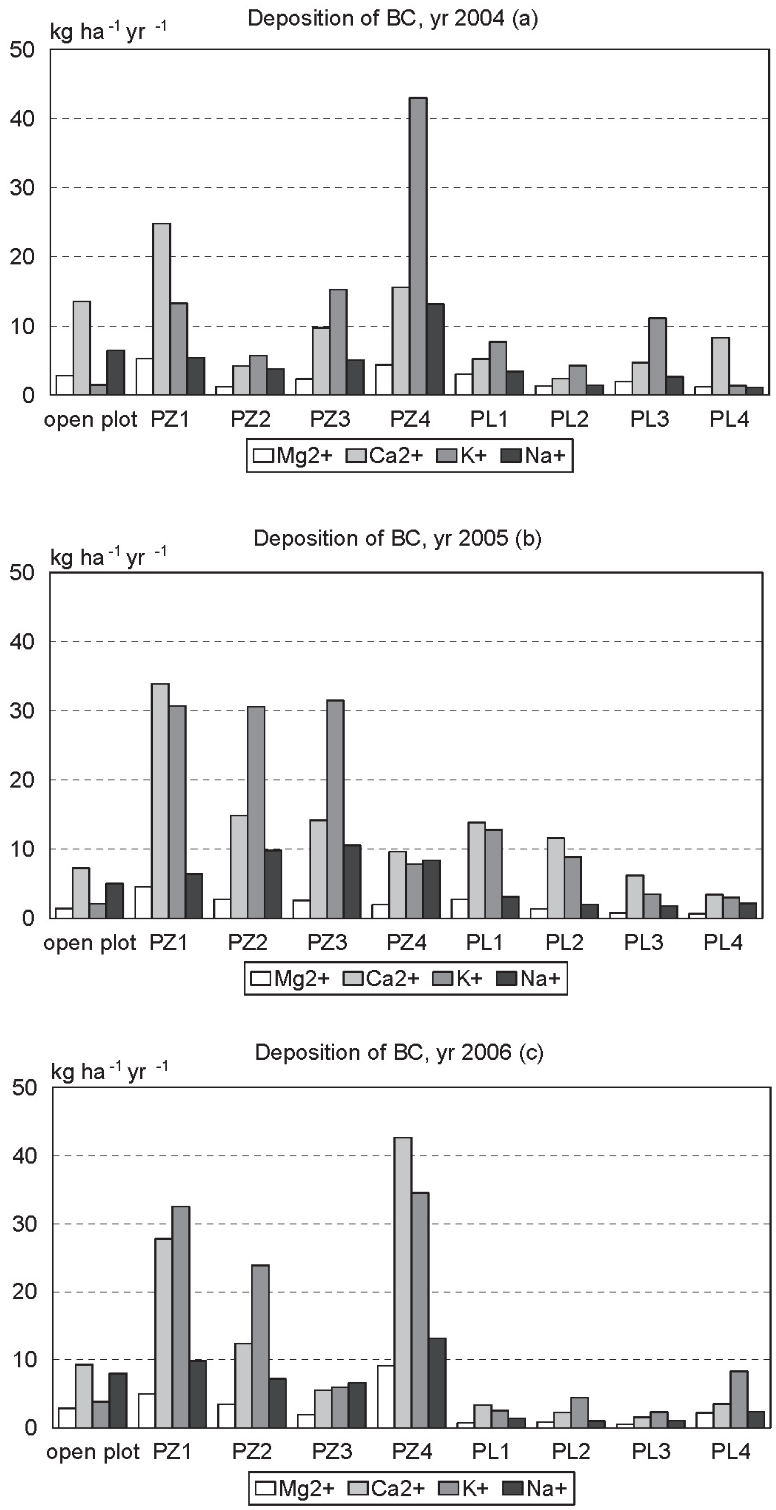

Fig 7. Deposition of basic cations (BC) in 2004(a), 2005(b) and 2006(c)

are influenced by interaction with the stand biomass and they need not reflect the true deposition of basic ions into the stand.

Translated by D. Kúdelová and J. Škvarenina

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Chemizmus podkorunových zrážok a atmosférická depozícia v klimaxovom subalpínskom smrekovom lese Biosférickej rezervácie Poľana, Slovensko

Súhrn

Predložená práca je zameraná na zisťovanie fyzikálno-chemických vlastností zrážkových vôd (pH, elektrická vodivosť), na analýzy koncentrácií vybraných chemických komponentov (H^+, SO_4^{2-}, NO_3^-, K^+, Na^+, Mg^{2+}, Ca^{2+}, NH_4^+) a na výpočet imisných atmosférických depozícií hlavných elementov (H, S, N a bázických prvkov). Objektom práce bola horská smrečina 7. smrekového vegetačného stupňa, skupiny lesných typov Sorbeto-Piceetum, Acereto-Piceetum na lokalite Predná Poľana. Z práce možno vyvodiť nasledovné závery:

V priebehu sledovaného obdobia 2004–2006 možno pozorovať rast pH hodnôt a ich mierny pokles v roku 2006, takmer na všetkých plochách. Lyzimetrické vody v porovnaní s podkorunovými zrážkami sú kyslejšie. Najnižšia kyslosť bola preukázaná na voľnej ploche (5,57).

Koncentrácie H^+, SO_4^{2-}, NO_3^- a NH_4^+ sú najnižšie na voľnej ploche. Lyzimetrické vody sú viac koncentrované ako podkorunové zrážky. V rámci podkorunových zrážok sa najväčšími koncentráciami vyznačuje mladina. Za sledované obdobie 2004–2006 možno pozorovať pokles koncentrácií sledovaných komponentov.

Na sledovaných plochách sme zaregistrovali značné obohatenie koncentrácií bázických katiónov v porastových zrážkach (najväčšie obohatenie vykazuje pôdny roztok) v porovnaní s voľnou plochou. Táto skutočnosť indikuje nebezpečný jav vylúhovania bázických živín z organického materiálu. Pri sledovaní hodnôt bázických katiónov na výskumnej ploche Predná Poľana možno vidieť, že na voľnej ploche má najväčšie zastúpenie Ca^{2+} (0,77 mg l^{-1}) a Na^+ (0,51 mg l^{-1}), v podkorunových zrážkach sú to K^+ a Ca^{2+}.

Na výskumnej ploche Predná Poľana boli zistené značné hodnoty depozície síry, celkového dusíka a vodíka. Najnižší depozičný vstup vykazuje voľná plocha. Depozícia v lyzimetroch všetkých zisťovaných prvkoch je nižšia ako v poraste, hoci koncentrácie mali opačnú tendenciu.

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Phenology of pedunculate oak (*Quercus robur* L.) in the Zvolen basin, in dependence on bio-meteorological factors

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Abstract

Škvareninová, J., Domčeková, D., Snopková, Z., Škvarenina, J., Šiška, B. 2008. Phenology of pedunculate oak (*Quercus robur* L.) in the Zvolen basin, in dependence on bio-meteorological factors. *Folia oecol*., 35: 40–47.

The paper presents the course of phenophases in pedunculate oak (*Quercus robur* L.) in the Zvolenská kotlina basin. The phenophases were observed according to the SHMÚ methodology. There were evaluated vegetative (leaf unfolding, bud-burst, leafing, autumn leaf discolouration, leaf-fall) and generative (flower buds, flowering, end of flowering, ripening of fruits) phenophases over 2003–2006, in relation to the bio-meteorological variables. The average day of onset of leaf bud swelling was the April 12, the blossoming phase began towards April 24. Significant for starting these phenophases was the mean daily air temperature not sinking below 0 °C. The spring generative phenophases were launched when the effective air temperature was higher – at 8 °C. The flower buds were observed towards May 6. The flowering started on about May 10. The autumn leaf discolouration started in average on October 9 and the leaffall on November 8. The beginning of these phenophases also depended on temperature and precipitation conditions in the growing season. The ripening of fruits was influenced by temperature and the rate of solar radiation, but it may be conditioned by genetic properties, too. Ripening of pedunculate oak fruits was observed towards September 19. The autumn phenophases finished sooner in dry years than in wet years.

Key words

phenology, Pedunculate Oak (*Quercus robur* L.), temperature sums

Pedunculate Oak (Common Oak, English Oak (*Quercus robur* L.)) belongs to the most productive woody plants in forest stands. Sharing with 13.5% (Anonymus, 2003) on the species composition of Slovak forests, it is the second most abundant woody plant in the country. In the Zvolenská kotlina, basin, oak trees are present in high amounts from the hill slopes to the basin bottom, in spite of an evidently continental character of the territory (Magic, 1997). Pedunculate oak tolerates appropriately also low temperatures; the discussed territory, however, only contains small remnants of the original hornbeam-oak forests in areas that have been declared protected. One of these localities with occurrence of old pedunculate oak trees is the Arboretum Borová hora of the Technical University in Zvolen. We have subjected the fragments of the original stands in this locality to phenological observations.

In context of the ongoing climate development and supposed climate change, phenological observations would contribute to recognising development of biotic components of the environment and changes in spatial distribution of woody plants, Defila (1996), Schieber (2006), Schieber and Kováčová (2000), Štefančík and Cicák (1991).

Material and methods

Our analysis of observations of phenological events in pedunculate oak in the Zvolenská basin has been elaborated for the period 1990–1994 (Škvareninová, 2003).

We carried out phenological observations in a fragment of pedunculate oak stand, cca 70–75 years in age. As for topography, the plot is situated on the SW of the Zvolenská upland, a sub-unit of the Zvolenská basin area. Character of the territory is hilly, altitude ranging 290–380 m asl, prevailing orientation N-NW. The long-time mean annual temperature is 8.2 °C, the mean annual precipitation total is 757 mm (Labanc et al., 1992).

The plot was selected in an area with natural occurrence of pedunculate oak and it comprised ten oak trees. The particular vegetative and generative phenophases were observed and recorded in years 2003–2006, following the methods proposed by the Slovak Institute of Hydrometeorology (SIHM) in Bratislava (Anonymus, 1984). We recorded the following phenophases and their stages:

- vegetative: leaf bud swelling (LBS 10%, 50%, 100%), bud-burst (BB 10%, 50%, 100%), leafing (L 10%, 50%, 100%), leaf discolouration (LD 10%, 50%, 100%), leaf-fall (LF 10%, 50%, 100%)
- generative: flower buds (FB 10%, 50%, 100%), flowering (F 10%, 50%, 100%), blossom fall (BF 100%), running to seed (RS 10%, 50%, 100%).

The observation intervals for monitoring the spring phenophases were short (2–3 days), the autumn phenophases were observed in general once a week. In case of spring phenophases we recorded their start, that means the day when at least 10% of the individuals had reached the concerned phase. The general arrival was considered the day when the phenophase could be observed in 50% trees. The full arrival meant that the phenophase could be observed in 100% trees. To facilitate the data processing, the phenophases-related dates were provided with the absolute numbers ordering the days since the January 1.

The start of particular phenological phases is influenced by several biometeorological factors. Governing is the sum of mean daily air temperature values. We evaluated the impact of sum of mean temperatures exceeding 0 °C (TS0), 5 °C (TS 5), 8 °C (TS8), and 10 °C (TS10).

Results and discussion

Course of spring phenophases

The objective of this work was to evaluate pedunculate oak phenophases in connection to bio-meteorological conditions at the site in 2003–2006. There were observed differences in start and course of spring phenophases between the individual years – air temperature was the decisive factor controlling the phase start and duration. For start of spring phenophases is necessary an appropriately long raising air temperature in several days previous to the start, and reaching the temperature sum appropriate for the activation. The timing of spring phenophases over the study period as well as statistical characteristics are summarised in Table 1. For each phenophase we calculated sums of mean daily air temperatures for threshold temperatures at which the phenological processes are activated most frequently. The average sums of effective temperatures necessary for activation of the phenophases are in Table 2. Sums of temperatures exceeding 0 °C at start of spring vegetative phenophases in years 2003–2006 are in Fig 1.

The leaf bud swelling in the study period was dated on average from the early days of April (5.4.) to the mid of this month (16.4.). The general arrival was observed on April 12, on average. In case of this phase we recorded the biggest differences in phase length (9–19 days), and also in the start timing between the years. This fact has also been confirmed with variation coefficient values ranging from 2.60% to 4.82%. Instable, considerably fluctuating, weather in the spring caused that in 2003 lasted this phase 18 days, in spite of its early beginning. In the last two years was the duration of this phase 6–8 days only. The start of coming this phenophase (LBS 10%) depends on the temperature limit of 0 °C (TS0 = 152.2 °C) with the lowest measure of variability and uniform course of values. The temperature sums (TS5) exceeding 5 °C assign to this phase a temperature sum of 34.7 °C on average. Low and zero values of temperature sums over 8 °C and 10 °C in individual years might result in distorted values when evaluating temperature demands of this woody plant.

The first manifestations of bud-burst were observed in first days of the third ten-day period of April, the variation range was 4 days. The average timing of arrival the phenophase in 50% was April 24, at a temperature sum TS0 = 332.2 °C. This phenological stage also depended on occurrence of higher average air temperatures exceeding 5 °C (TS5 = 124.1 °C), which was indicated by the smallest variation coefficients of the temperature sums. The variation range of this phenophase course was 8–11 days. The beginning of leaf unfolding (10%) occurred on May 3, on average. The average date of general leafing (50%) was May 7, the total leafing was observed on May 10, on average. Comparing with the observation results obtained in years 1990–1994 (Škvareninová, 2003) according to that the average date of 50% leafing was May 6, we can see that this parameter, shifted by one day backwards, does not indicate a change in climatic conditions in this territory. Such change could only be indicated by evaluation over longer time periods. For the whole Slovak territory and the years 1986–1995 (Kamenský and Braslavská, 1999) the average beginning of leafing phenophase was reported on April 30, which is 3 days earlier compared to our results. The phenophase length was from 6 to 10 days. The earliest start was recorded on April 24, year 2005. The phase of general leafing occurred at a temperature interval of 0–5 °C, when the course of temperature sums was most equalised (TS0 = 490.5 °C, TS5 = 222.4 °C) and the variation coefficients values were lowest (8.9–9.3%). In the spring phenophases, the highest variability was observed in the phase bud swelling. The other two spring vegetative phases (leaf bud-burst and leaf unfolding) had considerably lower variability (1.09–2.77%), which allows

Table 1. History of spring phenophases in Pedunculate Oak (*Quercus robur* L.) and their statistical characteristics in years 2003–2006 (x – arithmetic mean, s_x [%] – standard deviation)

Year	2003	2004	2005	2006	x	s_x [%]
Phenophase			Julian Days (date)			
LBS 10%	87	97	95	100	95 (5. 4.)	4.82
LBS 50%	99	105	99	103	102 (12. 4.)	2.60
LBS 100%	105	110	101	108	106 (16. 4.)	3.39
BB 10%	108	112	109	111	110 (20. 4.)	1.58
BB 50%	114	116	112	115	114 (24. 4.)	1.48
BB 100%	118	119	116	118	118 (28. 4.)	1.09
L 10%	123	126	119	123	123 (3. 5.)	2.49
L 50%	127	128	122	132	127 (7. 5.)	2.49
L 100%	131	131	125	132	130 (10. 5.)	2.77
FB 100%	124	127	125	127	126 (6. 5.)	1.30
F 100%	127	129	131	130	130 (10. 5.)	1.48
BF 100%	131	132	138	139	135 (15. 5.)	3.54

Table 2. Average sums of effective temperatures on days with temperature exceeding 0 °C (TS0), 5 °C (TS5), 8 °C (TS8), 10 °C (TS10) over the period 2003–2006

Spring Phenophase	Average sums of effective temperatures for days exceeding 0 °C, 5 °C, 8 °C, 10 °C			
	TS0	TS5	TS8	TS10
	[°C]			
LBS 10%	152.20	34.68	6.90	1.23
LBS 50%	197.85	52.40	12.63	2.98
LBS 100%	237.90	70.63	19.80	4.93
BB 10%	287.13	99.85	37.03	14.15
BB 50%	332.23	124.05	49.98	20.70
BB 100%	373.58	147.90	63.55	28.03
L 10%	442.00	191.33	91.98	46.60
L 50%	490.53	222.35	112.50	60.28
L 100%	542.28	256.60	136.25	77.30
FB 100%	483.03	217.35	109.00	57.73
F 100%	523.55	240.38	122.50	65.85
BF 100%	608.35	296.43	161.30	93.70

Table 3. Start of autumn phenophases in Pedunculate Oak (Quercus robur L.) and their statistical characteristics in years 2003–2006 (x – arithmetic mean, s_x [%] – standard deviation)

Years	2003	2004	2005	2006	x	s_x [%]
Phenophases			Julian Days (date)			
LD 10%	255	271	269	272	267 (24. 9.)	6.87
LD 50%	272	279	291	286	282 (9. 10.)	7.18
LD 100%	289	292	297	296	294 (21. 10.)	3.20
LF 10%	295	297	298	303	298 (25. 10.)	2.94
LF 50%	304	306	320	318	312 (8. 11.)	7.07
LF 100%	314	312	332	325	321 (17. 11.)	8.17
RS 10%	232	257	248	251	247 (4. 9.)	9.25
RS 50%	255	267	264	263	262 (19. 9.)	4.44
RS 100%	265	273	271	276	271 (28. 9.)	4.02

Table 4. Average sums of effective temperatures on days with temperature exceeding 0 °C (TS0), 5 °C (TS5), 8 °C (TS8), 10 °C (TS10) for autumn phenophases in years 2003–2006

Autumn Phenophase	Average sum of effective temperatures on days exceeding 0 °C, 5 °C, 8 °C, 10 °C			
	TS0	TS5	TS8	TS10
	[°C]			
LD 10%	2,927.5	1,956.8	1,426.6	1,098.0
LD 50%	3,110.0	2,063.3	1,488.8	1,135.1
LD 100%	3,207.1	2,105.4	1,507.6	1,143.9
LF 10%	3,244.3	2,121.0	1,513.9	1,145.7
LF 50%	3,319.4	2,149.9	1,529.0	1,154.7
LF 100%	3,360.4	2,164.6	1,534.2	1,155.7
RS 10%	2,630.5	1,758.6	1,287.6	997.6
RS 50%	2,865.1	1,917.0	1,400.2	1,026.8
RS 100%	2,574.4	1,706.2	1,237.4	949.2

it was shifted to September 29. The average date of start of leaf discolouration in Slovakia in the decade 1986–1995 (Kamenský and Braslavská, 1999) was calculated September 19, which is 20 days earlier compared to our results. The start of this phenophase (10%) is dependent on the weather course in summer months. For the full arrival (100%) it was necessary to reach the appropriate sum of effective temperatures. This sum was highest in year 2003 (TS0 = 3,318 °C), lowest in 2004 (TS0 = 3,050 °C).

The leaf fall is influenced by several factors. Apart from abrupt drops in temperature, there are genetic predispositions expressed through delayed leaf-fall in the same individuals in each year. There can be also considerable contribution of wind, significantly accelerating the rate of the process. The leaf-fall occurred in average from October 25 to November 17. The earliest arrival of this phenophase was recorded in 2003, the latest in 2005. In all the study years, the total leaf fall was observed at almost the same values of temperature sum with average exceeding TS0 = 3,360.4 °C. Compared to the period 1990–1994 (Škvareninová, 2003), the general leaf fall was shifted almost 30 days later.

The fruit maturity in oak is manifested through brown-coloured acorns releasing from the cupules. Based on our observations, we have dated the average beginning of this phenophase on September 4, and the total ripeness on September 28. In comparison with the observations carried out in 1986–1995 (Kamenský and Braslavská, 1999), this phenophase arrived 15 days earlier; in comparison with observations carried out in 1990–1994 (Škvareninová, 2003), it was 9 days earlier. The beginning of this phase was observed earliest in 2003, on August 20, but the phase was also us to conclude that their course was quite equalised, thanks to uniform temperature course without abrupt fluctuations. The probable cause of such a low variability was uniform temperature course in late spring in the preceding year. The preliminary results show that there were no remarkable shifts in beginning of spring vegetative phenophases. Their arrival and course is controlled by character of weather. In Fig 1 we can see that in 2004, the spring phenophases came at higher effective air temperatures, exceeding 0 °C, than in the other years, which was caused by the cold end of winter. The year 2003 was characterised by mild temperatures towards the end of winter and by a relatively warm beginning of spring. This fact was reflected in the low sum of effective temperatures conditioning the arrival of swelling and burst of leaf buds. In the study period we did not record a remarkable increase in effective temperature sum at the beginning and during the course of individual phenophases.

The flower buds came together with leaf unfolding. Fully developed male flowers, but without pollen release yet, occurred towards May 6, on average. The length of this phenophase in the study years was only 3–4 days. The start was always dated very similarly – which has also been confirmed with very similar values of variation coefficient (1.3–1.92%). The obtained values of temperature sums suggest as decisive for this phase at 50% the value 8 = 101.2 °C, at 100% the value of TS8 = 109 °C – with the most uniform values and the lowest variation coefficients of temperature sums ranging from 8.9% to 10.4%.

The flowering of pedunculate oak starts immediately after the total, 100% leafing. It is the phenophase with the most stable arrival and the lowest variability (s_x% = 1.30–1.48). The phase of full 100% average flowering was recorded on May 10, after reaching the sum TS8 = 122.5 °C. At that time we calculated the lowest value of variation coefficients of temperature sums (5.4%), and recorded the smallest differences between the temperature sums in the individual years. The length of flowering ranged from 2 to 4 days, which is in comparison with the period 1990–1994 (Škvareninová, 2003) less by 2–4 days.

The full running to seed occurred on May 15, on average, and it lasted quite shortly, 3–7 days after having reached the TS8 = 161.3 °C. The spring generative phenophases are characterised with a short time history, and their arrival is controlled with air temperature average values exceeding 8 °C.

Course of autumn phenophases

The arrival dates of autumn phenophases in years 2003–2006 are in Table 3, the sums of effective temperatures are in Table 4.

The first autumn vegetative phenophase, signalising the end of photosynthetic activity, is leaf discolouration (yellowing). This phase started on September 24, on average, and lasted up to October 21. The earliest start was recorded in the year 2003, when the first yellow leaves were already observed on September 12. The latest was the beginning dated in 2006, when

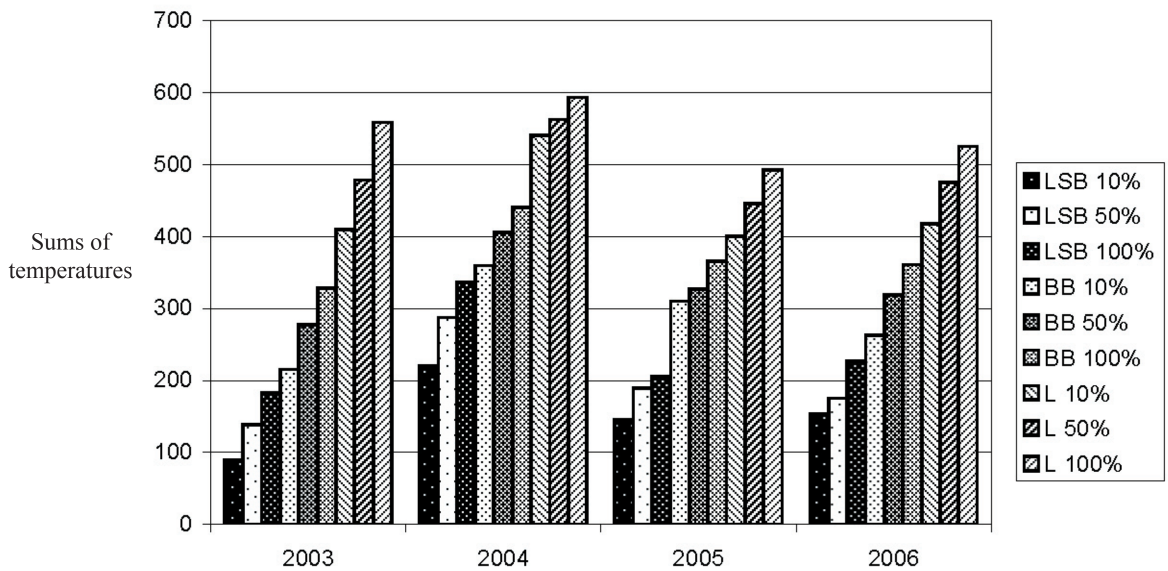

Fig 1. Sums of temperatures exceeding 0 °C at start of spring vegetative phenophases in Pedunculate Oak (*Quercus robur* L.) in years 2003–2006

the longest one (34 days). On the other hand, the latest beginning was recorded in year 2004 (September 14), and the phenophase length was shortest – 22 days. In spite of the fact that the date of beginning fruit maturity was shifted towards the end of the summer period (the first days of September), the average length of this phenophase was maintained without changes. The autumn phenophases are also characterized with higher variability (s_x = 2.94–9.25%), caused probably by abrupt temperature changes and drops below the freezing point in this period.

The beginning of leaf discolouration in 2003 (10%) was connected with a very warm end of summer, which has also been confirmed with a high temperature sum (Fig 2). The following autumn phenophases in all the study years arrived with almost equal sums of effective temperatures exceeding 0 °C, without remarkable changes. We can conclude that there is neither warming a prolonged vegetation period in this season. The preliminary results obtained in evaluation of course of autumn phenophases of pedunculate oak in the Zvolenská kotlina basin show that these changes are not dependent on air temperature only but also on a range of factors involving, according to Hofman (1957), the length of solar radiation and moisture conditions in summer, abrupt temperature changes in autumn, and, according to our observations, strong wind, too. Hejtmánek (1958) states that the light intensity and site quality have also important role for ending the growing cycle. The autumn phenophases, unlike the spring ones, are more influenced by precipitation total over the growing season. In years with lower summer precipitation, the autumn phenophases are dated earlier. In our study period, the earliest was the timing in 2003, because this year was very poor in precipitation. The autumn phenophases were characterised with higher variability than the spring ones, which is also documented by the values of variation coefficient ranging from 2.94% to 9.25%.

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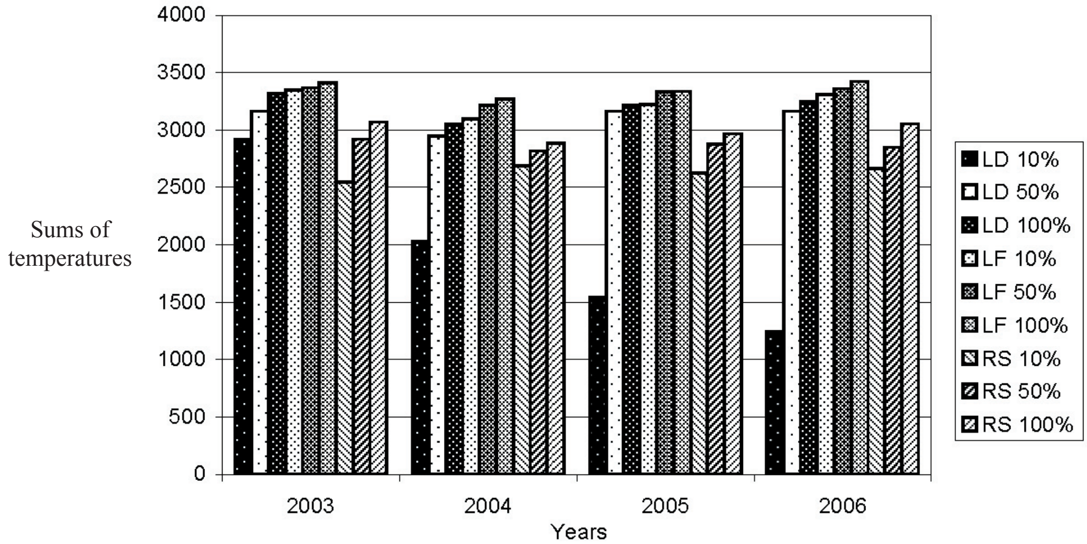

Fig. 2. Sums of temperatures exceeding 0 °C at start of autumn vegetative phenophases in Pedunculate Oak (*Quercus robur* L.) in years 2003–2006

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Vybrané fenofázy duba letného (*Quercus robur* L.) v Zvolenskej kotline vo vzťahu k biometeorologickým faktorom

Súhrn

Z výsledkov fenologických pozorovaní duba letného v Zvolenskej kotline v rokoch 2003–2006 sme zistili odlišný nástup a dĺžku trvania jarných fenofáz v jednotlivých rokoch. Rozhodujúcu úlohu zohráva teplota vzduchu. Všeobecný nástup pučania listových púčikov prebiehal v sledovaných rokoch v prvej polovici apríla, priemerný deň nástupu bol 12. apríla. Pre začatie procesu rastu púčikov duba je rozhodujúci vzostup priemerných denných teplôt vzduchu nad 0 °C, kedy teplotná suma TS 0 dosiahla hodnotu 197,85 °C a zaznamenali sme najnižšiu mieru variability. Pučanie listových púčikov dosahuje vyššie hodnoty variačných koeficientov (2,60–4,82 %), čo súvisí s väčším výkyvom teplôt v skoršom jarnom období. Fáza všeobecného rozpuku listových púčikov pripadá v priemere na 24. apríl. Začína pri priemernej teplotnej sume TS 0 = 332,2 °C, a je už podmienená aj nástupom vyšších priemerných denných teplôt vzduchu nad 5 °C (TS 5 = 124,1 °C). Priemerný dátum nástupu všeobecného zalistenia (50 %) pripadá na 7. máj a nastáva v teplotnom intervale 0–5 °C pri dosiahnutí sumy teplôt TS 5 = 222,4 °C.

Z predbežných výsledkov pozorovaní vyplýva, že nedochádza k výraznému posunu termínov nástupu vegetatívnych fenofáz oproti predchádzajúcim rokom. Pri fenofáze pučania listových púčikov sme zaznamenali najväčšiu variabilitu v dĺžke trvania fenofázy, ako aj v časovom nástupe v jednotlivých rokoch. Pri nástupe fenofáz sme nezaznamenali výraznejší nárast sumy efektívnych teplôt.

Jarné generatívne fenofázy sa vyznačujú krátkym časovým priebehom a na ich aktivovanie je potrebná priemerná teplota vzduchu nad 8 °C. Potvrdzujú to najnižšie variačné koeficienty a vyrovnané hodnoty teplotných súm TS 8.

Priemerný začiatok žltnutia listov nastáva 9. októbra, opad listov 8. novembra. Z predbežných výsledkov vyhodnotenia priebehu jesenných vegetatívnych fenofáz duba letného v Zvolenskej kotline je zrejmé, že nastupujú neskôr oproti predchádzajúcim rokom, ale ich dĺžka sa výrazne nemení. Zrelosť plodov sa výrazne posunula na koniec letného obdobia, priemerný začiatok fenofázy nastáva 19. septembra, ale dĺžka trvania ostáva nezmenená.

Zistili sme, že jesenné fenofázy nesúvisia len s teplotami vzduchu, ale ich výrazne ovplyvňuje dĺžka slnečného žiarenia a vlhkostné pomery počas letných mesiacov, náhle zmeny teploty v jesennom období a sú čiastočne podmienené aj genetickými vlastnosťami jedincov, čo sa prejavilo odchýlkami fenofáz na tých istých jedincoch v každom roku. Jesenné fenofázy nastupovali v suchých rokoch skôr, ako v rokoch bohatých na zrážky. Takmer vyrovnané sumy efektívnych teplôt vzduchu počas štvorročného obdobia dokazujú stálosť klimatických podmienok.

Výsledky fenologických pozorovaní duba letného je možné využiť na rozšírenie poznatkov o jeho nárokoch na podmienky prostredia a tiež ako bioindikátor klimatických zmien pri vyhodnotení dlhšieho radu pozorovaní.

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Morphological variability of fruits in the European chestnut (*Castanea sativa* Mill.) seed progenies in the Castanetarium Horné Lefantovce

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Abstract

Tokár, F. 2008. Morphological variability of fruits in the European chestnut (*Castanea sativa* Mill.) seed progenies in the Castanetarium Horné Lefantovce. *Folia oecol*., 35: 48–59.

The paper provides a comprehensive survey of parameters describing morphological variability of chestnut fruits (weight, shape index, colour, size of hilum, fruit partition, colour of kernel, ease of seed coat peeling, taste of kernel) for 86 seed progenies of European chestnut (*Castanea sativa* Mill.) planted in the Castanetarium Horné Lefantovce. The research was being conducted in 1996–1998. The age of seed progenies at the beginning of the survey was 30–32 years. The results revealed that many morphological traits were dependent on the seed progeny's provenance (selection tree, locality and sub-region of cultivation) and on climate history in the relevant year.

Key words

morphological traits of fruits, seed progenies, *Castanea sativa* Mill.

Introduction

The cultivation success of European chestnut (*Castanea sativa* Mill.) in climatic conditions of Slovakia is close dependent on thorough recognition of its biological and ecological properties. To meet this requirement, in 1965 was established the experimental Castanetarium in Horné Lefantovce (Benčať and Tokár, 1971), coordinated by the Arboretum Mlyňany, Institute of Woody Plants Biology SAS (Fig 1). The main goal was centralisation of comprehensive research on biology, ecology and production of European chestnut trees into uniform ecological site conditions.

At present, the Castanetarium Horné Lefantovce represents the precious centralised national gene pool of European chestnut, requiring a special attention in both research and forest management as well as specific management methods. For this reason, with forest management plans updated in 1999, the territory has been assigned to special-purposed forests.

Apart from biological manifestations of the examined woody plant, the research in the Castanetarium Horné Lefantovce was also aimed at verification of genetic stability or variability of morphological parameters of fruits in selected seed progenies.

In this work we present ecological description of the Castanetarium and the results of fruit morphological variability for 86 seed progenies of European chestnut (*Castanea sativa* Mill.) belonging in the year 2001, at their age of 35 years, into five categories (Tokár, 2003).

Material and methods

Ecological description of the Castanetarium

The Castanetarium having an area of 14.38 ha is situated at 220–250 m asl, north of the Nitra town, cadastre territory Horné Lefantovce, locality "Ferdinandka" in the Tríbeč Mts. It was established in years 1965–1970, on former agricultural land, by the founder Institute of Woody Plants Biology SAS in Nitra. As for administration, it belongs to the national forests, Forest Enterprise Topoľčianky, Forest Management Unit Nitrianska Streda, Forest District Lefantovce.

The climate is warm, type A. At the time of establishment, the soil type was brown soil loamy or clayey-loamy (Benčať and Tokár, 1971). Under a 35-year influence of the planted chestnut stands, the soils have been converted to luvisols with the typical illimerisation horizon (Tokár and Kukla, 2006).

As for phyto-geography, the Castanetarium belongs to the West Carpathian area (Carpaticum occidentale), Pre-Carpathian region (Praecarpaticum).

Before the plantation of chestnut trees, the territory had been used as arable land. The succession processes, for 35 years associated with growing woody plants, have resulted in formation of forest communities of the third (oak-beech) forest vegetation tier. In the phytocenoses we identified 86 mostly mesotrophic species, characteristic for the group of forest types Fagetum pauper inferiora (Tokár and Kukla, 2006).

In 1965–1970, the Castanetarium was planted with 57,056 European chestnut plants configured as corresponding to various stand formations, mostly as seed progenies (86 seed progenies making a total of 24,145 trees, Fig 1). The tree number in the year 2001, at the age of 35 years was 13,589 chestnut trees, representing 23.82% of the original plants. This final number has been reached with repeated tending (thinning six times) and sanitary cuts (damaged and dry trees).

Fruit morphology

We were conducting a thorough survey on weight and perception-related variability of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) assembled into the Castanetarium Horné Lefantovce, from 123 selection trees from 12 localities in Slovakia (Benčať and Tokár, 1971). In 1996, 1997 and 1998 we performed detailed evaluations of fruit morphology for 86 seed progenies at their physical age of 30–32 years. This problem was studied also in the framework of the diploma work (Perháčová, 1999). However, some phenological manifestations as the first flowering (types and anomalies of inflorescence, the first fruits, types of fruits grouping, timing of maturity, damage by late frosts), we also recorded during the development (growth) of the seed progenies and grafted trees concentrated in the clone orchard in the Castanetarium.

The fruits of European chestnut were assorted into the following weight classes:

	Weight
Very light	less than 4.1 g
Light	4.2–4.9 g
Medium weighty	5.0–5.5 g
Weighty	5.6–6.0 g
Very weighty	more than 6.1 g.

The shape was classified based on the shape index (fruit width to the fruit length) into the following shape categories:

	Index
Triangular	less than 0.90
Round	0.91–1.04
Narrow elliptic	1.05–1.15
Broad elliptic	1.16–1.30
Very broad elliptic	above 1.31.

Immediately after the collection we examined the colour:
- Yellowish-red
- Brown-red
- Brown
- Brown-black.

Another important morphological trait of chestnut fruits is the size of hilum:
- Small
- Medium
- Large.

The fruit partition was evaluated as:
- Without concretions (single fruit)
- Partially grown together (short septa)
- Entirely grown together (multi-seed fruit) fully.

The colour of kernel was evaluated as:
- White
- Creamy-white
- Yellowish.

Seed coat peeling was classified as:
- Very good
- Good
- Bad.

For consummation is important the taste of kernel. It was categorised as:
- Sugar-like sweet
- Medium sweet
- Low sweet.

The seed progenies were labelled following the original labelling of the European chestnut selection trees in each of the Slovak localities monitored by Benčať (1960), based on morphological and chemical analysis of their fruits (Benčať et al., 1980; Benčať and Tokár, 1998; Benčať et al., 1999), in such a way as to enable assessment of their hereditary and genetic connectivity. The seed progenies were labelled as: Bratislava (BA), Častá (Č), Radošina (RA), Duchonka (D), Horné Lefantovce (HL), Jelenec (J), Tlstý Vrch (TV), Dolné Príbelce (DP), Stredné Plachtince (SPL), Modrý Kameň (MK), Rovňany (RO), Krná (K).

Morphometric and perception-related characteristics of fruits of European chestnut progenies were evaluated yearly, on samples consisting of 30 fruits from each seed progeny.

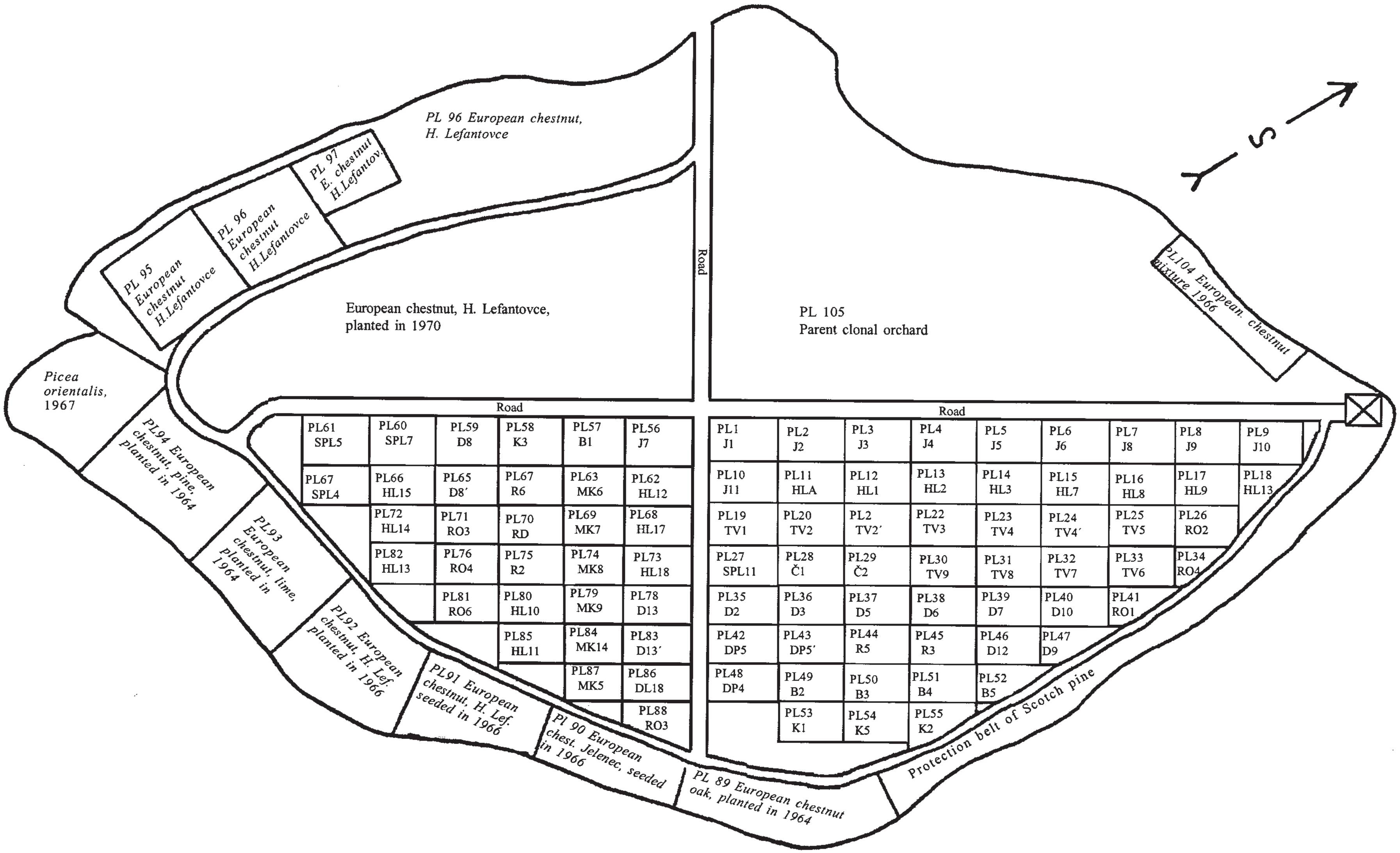

Fig 1. Situation draft of experimental plot Horné Lefantovce

The data about climate in 1996–1998, necessary for assessing the influence of climate on development of the fruit weight were provided by the Slovak Agricultural University in Nitra (Špánik et al., 2002).

Results

Fruit weight

An important morphological trait in fruits of European chestnut is their weight. Benčať and Tokár (1972, 1979a,b) report that the fruit weight is positively correlated with the height of plants and cultures of European chestnut up to three years after the plantation. Several-year observations allow us to conclude that the chestnut fruits in Slovakia have a mean weight of 7.3 g with variation range of 3.8–15.2 g and the variation coefficient of 27.8% (Benčať et al., 1980).

The statistical evaluation of weight of fruits from 86 seed progenies from European chestnut performed in 1996–1998 (tree age 30–32 years) resulted in classification into five weight categories, from very light up to very weighty (Table 1).

The experience gained with 12 localities, 4 subregions and 3 climatic years of growing European chestnut trees in the Castanetarium Horné Lefantovce, allows us to draw the following conclusions about the weight of chestnut fruits:

- Fruits of European chestnut seed progenies are characterised with high individual, local, regional and climate-related (annual) variability.
- The average weight of fruits from 86 seed progenies ranged from 2.20 g (Duchonka 13) to 8.44 g (Jelenec 11) with variation coefficient from 32% (Radošina 2) to 40.09% (Duchonka 10). The lowest (min) weight of individual fruits (1.40 g) was found in the seed progeny Duchonka 5 in year 1996, the highest absolute weight (14.40 g) was observed in seed progeny Duchonka 8 in 1998. The lowest variability of fruit weight (6.32%) was reached in seed progenies from the locality Radošina in 1997, the highest (40.09%) in seed progenies from the locality Duchonka in 1997. The both localities belong to the sub-region the Inovecko-Tríbečské Mts (Table 1).
- For development of fruits of European chestnut, the key important period was always from June to September. The values of climatic variables for 1996–1998 are listed in Table 2. We can see that temperature and precipitation values were different in the three different growing seasons. The difference in mean temperature was found biggest (1.9 °C) between years 1998 and 1996, the difference between the precipitation totals was found most conspicuous (51.2 mm) between 1998 and 1997. For the fruit development is also decisive the course of the two variables over the vegetation period. The year 1996 was favourable in precipitation, but September was rather cold. The years 1997 and 1998 were normal in temperature, but precipitation in July 1997 and September 1998 was remarkably above the normal. On the other hand, precipitation amounts in August and September 1997 and in June and August 1998 were deeply below the normal value. For the sound fruit development are favourable lower precipitation totals and less favourable (lowering the fruit weight) is more abundant precipitation. The critical value has been set to 30 mm. This value was not reached in August and September 1997, only.
- Apart from genetic factors, the weight of developing fruits in seed progenies is also influenced by the environmental (climatic) conditions and by the tree age. In case of the seed progenies, the first fruits were recorded already in 1971, at the tree age of 5 years. The fruits were found in 18 seed progenies (SP) from the localities Jelenec (6 SP), Horné Lefantovce (2 SP), Tlstý Vrch (6 SP), Častá (1 SP), Duchonka (3 SP). In 1972 fructified 21 seed progenies (SP) from the localities Jelenec (9 SP), Horné Lefantovce (4 SP), Tlstý Vrch (4 SP), Častá (1 SP), Duchonka (3 SP), in 1973 there were fructifying 33 seed progenies from Jelenec (9 SP), Duchonka (6 SP), Častá (2 SP), Tlstý Vrch (10 SP), Horné Lefantovce (5 SP), Radošina (1 SP), in 1974, 30 seed progenies from Horné Lefantovce (6 SP), Tlstý Vrch (9 SP), Jelenec (9 SP), Častá (2 SP), Duchonka (4 SP). The number of fructifying seed progenies and the weight of their fruits were always significantly dependent, apart from age, on ecological site conditions (primarily by light supply).

Since 1975 (age of seed progenies 10 years), the fruit collection has been being organised by the Forest Management Unit Nitrianska Streda.

Fruit shape

Based on their shape index (fruit width/fruit length), the fruits of European chestnut progenies were classified according to shape categories, from triangular up to very broad elliptic (Table 3, Figs 2, 3). The least frequent was the category of round-shaped fruits (1.16%), the most abundant were broad-elliptic (33.72%) and very broad elliptic fruits (32.56%).

Table 1. Weight variability of fruits of European chestnut seed progenies (SP) according to localities and sub-regions in Slovakia

Locality/ Subregion	Number SP	Years	Weight [g] Abs min	Abs max	x		v_x [%]	
					Min	Max	Min	Max
Bratislava	5	1996	1.50	9.40	4.79	6.18	15.26	35.60
		1997	1.50	9.50	4.46	5.62	15.91	26.47
		1998	1.80	11.80	4.73	7.93	17.01	26.99
Častá	2	1996	2.20	8.00	4.25	5.86	20.38	30.44
		1997	2.30	8.10	3.98	4.97	25.89	35.10
		1998	3.40	10.30	4.99	6.15	22.83	26.33
Malé Karpaty	7	1996	1.50	9.40	4.25	6.18	15.26	35.60
Mts subregion		1997	1.50	9.50	3.98	5.62	15.91	35.10
		1998	1.80	11.80	4.73	7.93	17.01	26.99
Jelenec	11	1996	2.20	9.40	4.05	5.87	17.03	34.04
		1997	2.00	9.60	3.82	8.44	10.78	38.90
		1998	1.80	9.60	3.40	5.43	19.70	28.90
Horné	16	1996	1.60	10.30	2.34	6.41	16.54	39.39
Lefantovce		1997	2.00	10.80	3.97	6.99	10.05	31.90
		1998	1.90	11.80	4.31	7.45	16.61	33.31
Radošina	5	1996	2.30	10.00	3.54	5.65	20.36	33.43
		1997	2.40	10.40	3.28	5.98	6.32	34.40
		1998	2.40	9.30	4.04	6.23	17.42	30.25
Duchonka	14	1996	1.40	10.40	3.49	6.15	20.38	39.35
		1997	1.50	10.40	2.20	6.51	17.48	40.09
		1998	1.69	14.40	3.97	6.93	13.53	31.23
Inovec – Tríbeč	46	1996	1.40	10.40	2.34	6.41	16.54	39.39
Mts subregion		1997	1.50	10.80	2.20	8.44	6.32	40.09
		1998	1.69	14.40	3.40	7.45	13.53	33.31
Tlstý Vrch	11	1996	1.90	10.10	3.67	5.90	16.43	39.98
		1997	2.20	8.40	2.54	6.80	10.12	38.46
		1998	2.40	13.20	4.16	8.31	15.36	25.35
Modrý Kameň	6	1996	2.10	8.30	4.10	5.49	16.05	31.96
		1997	2.30	8.60	3.97	5.35	12.02	25.80
		1998	2.50	10.70	4.32	6.85	21.20	30.24
Stredné Plachtince	4	1996	2.00	7.90	3.38	5.39	17.07	28.57
		1997	2.10	8.20	3.87	4.89	11.58	18.07
		1998	2.30	10.30	4.37	6.19	18.69	31.29
Dolné Príbelce	2	1996	3.20	10.30	5.40	6.18	15.26	29.89
		1997	2.80	10.20	4.62	5.62	17.36	57.85
		1998	3.10	9.90	4.71	6.80	17.01	19.99
Štiavnica – Krupina	23	1996	1.90	10.30	3.38	6.18	15.26	39.98
Mts subregion		1997	2.10	10.20	2.54	6.80	10.12	38.46
		1998	2.30	13.20	4.16	8.31	15.36	31.29

Table 1. Continued

Locality/ Subregion	Number SP	Years	Abs min	Abs max	Weight [g] x Min	x Max	v_x [%] Min	v_x [%] Max
Rovňany	6	1996	2.40	9.40	4.41	5.88	18.62	32.34
		1997	2.50	9.50	4.02	5.31	10.47	30.22
		1998	2.70	8.42	4.92	5.74	18.25	23.24
Krná	4	1996	2.10	9.48	3.16	5.70	23.08	29.78
		1997	2.30	9.60	3.19	5.04	25.01	32.26
		1998	2.60	8.40	4.65	5.67	20.14	23.58
Central Slovakia	10	1996	2.10	9.48	3.16	5.88	18.62	32.34
Mts subregion		1997	2.30	9.60	3.19	5.31	10.47	32.26
		1998	2.60	8.42	4.92	5.74	18.25	23.58
Slovakia	86	1996	1.40	10.40	2.34	6.41	15.26	39.98
		1997	1.50	10.80	2.20	8.44	6.32	40.09
		1998	1.69	14.40	3.40	8.31	13.53	33.31

Table 2. Climatic data for the years 1996, 1997, 1998

Year	Climatic data	Month VI	VII	VIII	IX	VI –IX
1996	Mean temperature [°C]	19.2	18.3	19.4	11.9	17.2
	Precipitation total [mm]	49.8	69.4	59.4	78.1	256.7
1997	Mean temperature [°C]	18.6	19.0	20.8	15.3	18.4
	Precipitation total [mm]	61.3	117.2	13.4	27.9	219.8
1998	Mean temperature [°C]	19.6	21.0	20.9	15.1	19.1
	Precipitation total [mm]	28.8	61.4	31.2	149.6	271.0

Table 3. Categorization of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) according to the fruit shape

Shape	Fruits of seed progenies of European chestnut (*Castanea sativa* Mill.)
Triangular	HL17, RA 3, K1
Round	D 9
Short-elliptic	BA 3, Č 2, J 2, 3, 4, 5, 8, 11, HL 3, 8, 11, 12, 13, 14, RA 5, D 2, 5, 6, 13, TV 4´, MK 6, 7, SPL 4, 5, K 3
Broad-elliptic	BA 1, 4, 5, Č 1, J 1, 9, 10, HLA 1, 9, 10, D 3, 7, 8´, 10, 12, 13´, TV 2, 2´, 3, 4, 6, 8, 9, MK 8, 9, 14, DP 4, K 2
Very-broad-elliptic	BA 2, J 6, 7, HL 2, 7, 15, 18, 19, RA 2, 6, D, D 8, 18, TV 1, 5, 7, MK 5, RO 1, 2, 3, 4, 4´, 6, DP 5, 5´, SPL 7, 11, K 5

Fig 2. Triangular shape of fruits in trees from the seed progenies of European chestnut (*Castanea sativa* Mill.)

Fig 3. Short elliptical shape of fruits in trees from the seed progenies of European Chestnut (*Castanea sativa* Mill.)

Fruit colour and size of hilum

The fruit colour and size of hilum are important morphological traits for visual classification of European chestnut fruits. The most frequent (53.49%) colouring was brown (Table 4), the most frequent (74.42%) hilum's size was medium (Table 5).

Rather rare were yellowish-red fruits and fruits with large hilum.

Table 4. Categorization of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) according to the fruit colour

Colour	Fruits of seed progenies of European chestnut (*Castanea sativa* Mill.)
Yellowish-red	BA 4, D 8´
Brown-red	BA 1, 2, J 2, 7,11, HL 3, 10, 12, RA 3, 5, D 2, 5, 6, 7, 8, TV 2, 2´, 8
Brown	BA 3, 5, Č 2, J 1, 3, 5, 6, 8, 9, HLA 1, 2, 9, 11, HL 13, 14, 15, 18, 19, RA 6, D 3, 10, 12, 13, 18, TV 1, 3, 4, 4´, 7, 9, MK 5, 6, 7, 14, SPL 4, 5, 7, 11, DP 4, 5, 5´, K 1, 2, 3, 5
Brown-black	Č 1, J 4, 10, HL 7, 8, 17, RA 2, D, D 9,13´, TV 5, 6, MK 8, 9, RO 1, 2, 3, 4, 4', 6

Table 5. Categorization of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) according to the hilum's size

Size of hilum	Fruits of seed progenies of European chestnut (*Castanea sativa* Mill.)
Small	Č 2, J 4, HL 8, RA 2, D 9, 18, MK 5, SPL 5, 7, 11, DP 5´, K 6
Medium	BA 1, 2, 3, 4, 5, Č 1, J 2, 3, 5, 6, 7, 8, 9, 10, 11, HLA 2, 7, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, RA 3, 5, 6, D, D 2, 3, 5, 6, 8, 8´, 12, 13, TV 1, 2, 2´, 4´, 5, 6, 7, MK 6, 7, 8, 9, 14, SPL 4, DP 5, RO 1, 2, 3, 4, 4´, K 1, 2, 3, 5
Large	1, HL 1, D 7, 10, 13´, TV 3, 4, 8, 9, DP 4

Perception-related properties of European chestnut fruits

The perception-related properties of European chestnut fruits mean: fruit partition, colour of kernel immediately after the fruit crosscutting, ease of seed coat peeling and taste of fresh kernel.

Fruit partition was evaluated based on the number and length of septa (Fig 4). The most frequent (38.37 were (Table 6) fruits fully concreted with septa (multiple-seed fruit). The rarest (27.91%) were separated fruits (single-seed fruit).

As for the kernel colour, the most frequent were seed progenies coloured creamy-white (76.65%), the rarest 9.30% were seed progenies with white-coloured kernel (Table 7).

Fig 4. Short elliptic shape, partition of fruits and pellicle intrustion from the left: multiseed fruit, fruit with pellicle intrusion and non-parted fruit in trees from the seed progenies of Europea chestnut (*Castanea sativa* Mill.)

Consumption value of European chestnut fruits is evaluated based on ease of seed coat peeling (separation of the hard pericarp from the kernel) and based on sugars amount. Confectioner's trade is interested in consumable chestnut fruits with easy coat peeling and high contents of sugars.

In our seed progenies are most abundant (45.35%) seed progenies producing fruits easy to peel, the least frequent (12.79%) are fruits with poor peeling (Table 8).

According to the taste of kernel (Table 9), the seed progenies belong to the categories sugar-like sweet (29.07%), medium sweet (60,46%) and low sweet (10.47%).

Table 6. Categorization of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) according to the fruit partition

Fruit partition	Fruits of seed progenies of European chestnut (*Castanea sativa* Mill.)
Single	B 1, 4, 5, J 1, 4, 5, 9, 11, RA D, 2, D 10, 13, 18, TV 2, 2´, 3, 4, 4´, 5, 6, 8, 9, MK 6, K 1
Partially grown together	BA 2, 3, Č 1, 2, J 2, 6, 8, 10, HL 11, RA 3, 5, D 2, D 3, 6, TV 7, MK 5, 7, 9, 14, SPL 4, 7, 11, DP 4, RO 1, 2, 3, 4, 4´, 5
Totally grown together	J 3, 7, HL A, 1, 2, 3, 7, 8, 9, 10, 12, 13, 14, 15, 17, 18, 19, RA 6, D 5, 7, 8, 8´, 9, 12, 13´, TV 1, MK 8, SPL 5, DP 5, 5´, K 2, 3, 5

Table 7. Categorization of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) according to the colour of kernel

Color of kernel	Fruits of seed progenies of European chestnut (*Castanea sativa* Mill.)
White	BA 5, Č 1, 2, J 7, HLA, TV1, MK 9, DP 5´
Creamy white	BA 1, 2, 3, 4, J 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, HL 1, 2, 3, 7, 8, 9, 10, 11, 12, 13, 14,17, 18, RA D 2, 3, 5, 6, D 2, 3, 5, 6, 7, 8, 8´, 9, 10, 12, 13, 18, TV 2´, 3, 4, 4´, 5, 6, 7, 9, MK 6, 7, 14, SPL 4, 7, DP 4, 5, RO 1, 2, 4, 6, K 1, 2, 5
Yellowish	HL 15, 19, D 13´, TV 2, 8, MK 5, 8, SPL 5, 11, RO 3, 5, K 3

Table 8. Categorization of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) according to the seed coat peeeling

Ease of seed coat peeling	Fruits of seed progenies of European chestnut (*Castanea sativa* Mill.)
Very good	BA 2, 3, 4, J 3, 8, 9, HL 3, 7, 8, 12, 13, 14, 18, 19, RA 2, D 5, 6, 7, 8´, 9, RA 2, TV 2´, 4´, 6, 9, MK 14, SPL 4, 5, 7, 11, RO 3, 4, 6, K 1, 2, 3
Good	BA 1, 5, Č 2, J 1, 4, 6, 7, 10, RA D, 3, 5, 6, D 2, 10, 13, 13´, 18, HL A, 1, 2, 5, 11, 15, 17, TV 1, 3, 5, 7, 8, MK 5, 6, 7, 8, 9, DP 4, 5´, RO 1, 2, K 5
Bad	Č 1, J 2, 5, 11, HL 9, 10, D 5, 8, TV 2, 4, DP 5

Table 9. Categorization of fruits of seed progenies of European chestnut (*Castanea sativa* Mill.) according to the taste of kernel

Taste of kernel	Fruits of seed progenies of European chestnut (*Castanea sativa* Mill.)
Sweet	Č 1, J 9, HL 1, 2, 3, 9, 19, RA 5, D 3, 5, 8, 13, 13´, TV 8, MK 5, 6, 7, 9, 14, SPL 4, 7, 11, RO 1, 2, K 5
Medium sweet	RA D, 2, 3, 6, D 2, 6, 7, 9, 10, 12, 18, TV 1, 2, 4, 4´, 5, 6, 9, MK 8, SPL 5, DP 4, 5, 5´, RO 4, 4´, 6, K 1, 2, 3
Low sweet	J 1, 5, 7, HL 13, D 8´, TV 2´, 3, 7, RO 3

Discussion

Our results show that biometric variables and perception-related properties of seed progenies of European chestnut assembled under homogenous ecological conditions (Tokár and Kukla, 2006) are very variable, and that they have not been stabilised yet. Some of them, eg weight and taste, are influenced to a considerable extent by the tree age and sociological status in the stand. Consequently, they can still be influenced with appropriate physiologically-oriented management methods. All the seed progenies have got through the same development, and to present, they have reached thick-pole stage (Figs 5, 6). The 35-year development of production and resistance potential of the seed progenies in the Castanetarium Horné Lefantovce has been mapped by Benčať and Tokár (1984), Tokár (1993, 1996, 2003), Tokár and Bolvanský (2002) and Tokár and Juhásová et al. (2004).

Fig 6. Seed progeny of European chestnut at the age of 30-years Duchonka 2 in Castanetarium Horné Lefantovce

Fig 5. View of 30-year–old seed progeny of European chestnut Tlstý Vrch 3 in Castanetarium Horné Lefantovce

Morphometric parameters of fruits of European chestnut seed progenies are significantly influenced by genetic factors, environment (controlled with stand phytotechnique) and climate history in the given year. Over the period of fruits development, the influence of these factors switches between profit for temperature or precipitation, primarily when these variables are exceeding their normal limits. Benčať (1968), Benčať and Bolvanský (1984) and Benčať and Tokár (1998) suggest that production of European chestnut fruits can be empowered in amount and quality by long dry period or, on the other hand, by too abundant precipitation, primarily in the flowering period when it represents a serious danger to the pollination process. Briccoli (1934 ex Benčať, 1960) suggests a value of 30 mm as the critical limit for monthly precipitation total for fruit development in this period. Also the contents of sugars in European chestnut fruits in Slovakia are favourably influenced by higher temperature and lower precipitation, namely when the second is uniformly distributed over the period of fruit development (Benčať et al., 1999).

Quantitative characteristics of fruits (weight, shape index, hilum size, number of seeds in the capsule) in seed progenies obtained by means of intraspecific and interspecific hybridisation (*Castanea sativa* × *Castanea crenata*) in Slovakia have been evaluated by Bolvanský (1988) and Bolvanský and Mendel (2001). The fruit weight was found positively correlated with mean temperature and precipitation total both over the vegetation period and all over the year.

The fruit morpho-metrics (shape index) and septa morphology in multiple-seed (grown together) fruits of European chestnut at four Slovak localities has been evaluated by Bolvanský and Užík (2005). The referred authors suggest that fruit quality of European chestnut is also possible to improve by means of hybridisation.

The shape index of fruits of European chestnut parent trees of the seed progenies in the Castanetarium Horné Lefantovce was evaluated by Benčať and Tokár (1998) in the original localities and sub-regions in Slovakia in 1976–1978. The lowest value (0.87) was obtained in the locality Stredné Plachtince, the highest (1.32) in Radošina. The Slovak average value was 1.06. Fruits of most selection were classified as narrow-elliptic (27.18%). Twelve of the seed progenies in the Castanetarium have preserved the shape categories of the original trees. We can conclude about genetic contingency.

From the other characteristics, for fruit consumption is primarily important taste of kernel. Consumers and confectioners seek edible chestnuts with higher or medium weight, brown-coloured, easy or very easy to peel and sugar-sweet to medium sweet kernel. Following the long term (9 years) evaluation of chemical composition of fruits of 123 selection (parent) trees growing in 12 Slovak localities (Benčať et al., 1999) and their seed progenies in the Castanetarium, we can suggest the following categorisation: low sweet (content of sugars less than 20.00%) – 23 trees (18.89%), medium sweet (sugars content 20.10–25.00%) – 76 trees (61.79%) and very sweet (sugars content 25.1–30.00%) – 24 trees (19.51%). The content of sugars in fruits of European chestnut is influenced by climatic conditions (more favourable is higher temperature and lower precipitation). The average values of sugars contents in the natural area of this woody plant range from 14–26% (Benčať, 1968). The results of chemical analyses of fruits of Slovak chestnut trees (Benčať et al., 1999) allow us to conclude that the content of sugars in Slovak chestnuts is not below the values from the natural area.

In the seed progenies are also present several botanic forms as var. spicata (Krná 1), f. rubida (Bratislava 1), f. elongata (Radošina 3).

Conclusions

The work evaluates biometric and perception-related traits (weight, shape index, colour, kernel colour, hilum size, ease of seed coat peeling, kernel taste) of fruits from 86 seed progenies of European chestnut (*Castanea sativa* Mill.) in the Castanetarium Horné Lefantovce, at the tree age of 30–32 years (1996, 1997 and 1998).

Several features are variable and not stabilised yet. Their values are influenced, apart from the tree age, also by genetic outfit (selection tree, locality, region), physiologically oriented cultivation methods, and mostly by weather conditions. The influence of these factors is positive either depending on temperature or depending on precipitation, mainly when the two variables are exceeding their normal values.

The average fruit weight ranged from 2.20 g (Duchonka 13) to 8.44 g (Jelenec 11), with variation coefficient from 6.32% (Radošina 2) to 40.09% (Duchonka 10).

According to the shape index, the fruits of seed progenies of European chestnut in the Castanetarium were classified to shape categories, from triangular to very broad-elliptic. The most frequent (33.72%) were broad-elliptic fruits.

As for the fruit colour, the most abundant (53.49%) were brown fruits, as for the hilum size, the most abundant (74.42%) were fruits with medium-sized hilum. Most seed progenies (38.37%) produce multiple-seed fruits, the biggest was proportion of fruits with creamy-white coloured kernel (76.74%).

The seed progenies of European chestnut produce most (45.35%) fruits easy to peel and most fruits (60.46%) with sweet kernel. The content of sugars in fruits of edible chestnut is influenced by climate (more favourable is higher temperature and lower precipitation).

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Morfologická variabilita plodov semenných potomstiev gaštana jedlého (*Castanea sativa* Mill.) v Castanetariu Horné Lefantovce

Súhrn

Práca zhodnocuje biometrické a senzorické znaky (hmotnosť, tvarový index, farba, zrastenosť, farba jadra, veľkosť jazvy, lúpateľnosť a chuť jadra) plodov 86 semenných potomstiev gaštana jedlého (*Castanea sativa* Mill.) v Castanetariu Horné Lefantovce pri veku 30–32 rokov (v r. 1996, 1997 a 1998).

Mnohé znaky sú variabilné a doposiaľ ešte neustálené. Ich hodnoty sú ovplyvnené okrem fyzického veku aj genetickou dispozíciou (výberový strom, lokalita, oblasť) a ďalšími fyziologicko-pestovnými opatreniami, najviac však klimatickými faktormi. Ich vplyv sa presúva v období vývinu plodu buď v prospech teploty alebo zrážok, a to najmä vtedy, keď vybočujú zo svojich normálnych hodnôt.

Priemerná hmotnosť plodov bola od 2,20 g (Duchonka 13) do 8,44 g (Jelenec 11) s variačným koeficientom od 6,32 % (Radošina 2) do 40,09 % (Duchonka 10).

Podľa tvarového indexu boli plody semenných potomstiev gaštana jedlého v Castanetariu Horné Lefantovce zatriedené do kategórií od trojuholníkovitých až k veľmi širokoeliptickým. Najviac je zastúpená kategória plodov širokoeliptických (33,72 %).

Z hľadiska farby plodov sú najviac zastúpené plody farby gaštanovej (53,49 %) a s jazvou strednej veľkosti (74,42 %). Najviac semenných potomstiev prináša plody zrastené (viacsemenné, 38,37 %) s krémovito bielou farbou jadra (76,74 %).

Semenné potomstvá gaštana jedlého prinášajú najviac plody s dobrou lúpateľnosťou (45,35 %) a polosladkou chuťou jadra (60,46 %). Obsah cukrov v plodoch gaštana jedlého ovplyvňujú klimatické podmienky (priaznivejšie vplývajú vyššie teploty a nižšie zrážky).

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Short communication

Usage possibilities of standard climatic characteristics for agrometeorological purposes

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Abstract

Klabzuba, J., Kožnarová, V. 2008. Usage possibilities of standard climatic characteristics for agrometeorological purposes. *Folia oecol.*, 35: 60–65.

This paper deals with the creation of 'optimal' weather model for the cultivation of rapeseed (*Brassica napus* L. var. *napus*). The starting point was parameterisation of negative meteorological conditions influencing growth, development and yield. We have processed, with the aid of standard climatologic characteristics of the semi-quantitative three-level evaluations, more than fifteen growing seasons with emphasis on unfavourable and high-risk meteorological factors (dryness or wetness during sowing, warm autumn, cold winter, high number of days with strong frost, low number of days with snow-cover, high number of days with precipitation during flowering). The result is a simple graphical model enabling us to express the accumulation of the effects of negative factors during the vegetation period.

Key words

rapeseed, growing season, yield formation, meteorological factors

Introduction and problems

In the Czech Republic, oil plants have in the last ten years become the second most important group of crops after cereals, which act as a significant stabilizer in agriculture economics. The most important role is played by rapeseed (Zukalová and Vašák, 2003). Rapeseed is a raw material for human consumption, oil meal, possibly oil cake or seeds comprising a major component of animal feed mixtures; biomass, used as green fodder or fertilizer; rapeseed oil, a possible material for chemicals industry (oil chemistry) and also a major source of renewable energy to replace fossil fuels and it also has an increasing role in the field of bio-fuels.

Its role is also indispensable in agro-ecology; it is a great pre-plant for cereals and it is a demanded interrupter of cereal sequences, increases soil yields, decreases the amount of weeds, decreases the usage of industrial fertilizer, is an alternative source of organic fertilizer, is an important food source for wild fauna, hinders soil erosion and ablation of nitrogen substances into groundwater. It further decreases soil pollution and water source pollution. Biomass is an important component of green fertilizer, especially due to its earliness. Cheap seeds, fast germination and growth even in lower temperatures enable the usage in green fertilization. Produced biomass is returned into the soil either directly (hay, pods, roots) or indirectly (animal production). In fats for human consumption only products of photosynthetic assimilation are lost from the circulation of nutrients.

Rapeseed (*Brassica napus* L. var. *napus*) has originally appeared in the Mediterranean area. Its current expansion reaches into all mild zone regions with significant cultivation areas on the Indian peninsula, in China, Western Siberia, Kazakhstan, in the European region from the Dnieper River to the British Isles, including Scandinavia, the Baltic region, Belarus, Northern America – especially in Canada, Argentina, Northern Africa and New Zealand.

The winter type is considerably less frequent and includes primarily Western and Central European regions, the Southern part of Scandinavia and Canada, Northern Caucasus, Western Ukraine, a part of Belarus, West and North of the USA.

Successful cultivation of rapeseed with high and stable yields and high quality is conditioned by several factors. One of the major factors is favorable weather during the full growing season, ie starting with soil preparation and sowing in August, ending with harvest in the following summer.

At the same time, the condition of small changes to weather in individual growing seasons is important, which is closely connected with the selection of appropriate climate of the growing areas. Almost all authors who dealt with rapeseed issues in long term studies (Fábry et al., 1991; Petr et al., 1991; Vašák et al., 1997; Zukalová and Vašák, 2003; Anonymus, 2003, 2004, 2005, 2006), agree that the ideal conditions are in regions belonging to the so called West European Atlantic climatic region with mild winters and adequate quantity of precipitation, evenly distributed throughout the year. Further East and Southeast Europe decreases oceanic character and increases continentality of the climate, which in its turn has an adverse effect of cultivation. Literature suggests that unstable weather conditions in each cultivation season in Germany result in yields not exceeding 20%, whereas in the Czech Republic it can be more than 40%.

The cultivation of rape in the Czech and Slovak Republics is successful everywhere where there is ploughed soil. It is possible to cultivate it effectively from lowlands to up to 700 m above sea level. The best conditions are in areas with average annual temperature of about 8° C (6.5–8.5 °C) and annual precipitation total of 500–750 mm. These conditions are best met by the potato and rape production type. The highest quality, yields and stability of production are in the potato regions, if all necessary requirements are met, especially nitrogen presence.

The vegetation period of rape in the Czech Republic lasts from 300 to 340 days, mostly 320 to 330 days; exceptionally it may be even one year in regions located more than 600 m above sea level.

Despite its exceptional plasticity, the rape does not tolerate soils which are wet for longer than a week during autumn or spring, as it is attacked by rots; sites with frost under –5 to –20 °C, as it freezes there. The same applies to sites where snow melts and glaciates for at least two weeks, to heavy soils with clods, as there rape will not grow during draught, further soils containing residues, especially sulfonylcarbamine with longer residual effects (Glean, Logran, Tel.), some triazin herbicides (eg Zeazin).

The climate requirements of rape during the vegetation phase are described by authors dealing with this issue as follows:

The vegetative, growth phases and generative, fertile phases occur during the ontogenesis, which lasts 11 to 12 months. Both phases overlap between November and February. This is the period of crypto-vegetation, when the growth of the above-ground biomass stops at already 5 °C. However, the roots often continue growing at 2 °C soil temperature. Changes in rape vegetation peak occur in this winter period, which advances by 2 stages in development into the generative phase. The yields can only be facilitated during vegetation growth, which occurs mainly at the end of March to beginning of May. Whilst the generative development is fairly continuous and most changes happen between February till May, the vegetative growth occurs in three phases.

The autumn vegetation phase – the most intensive growth, is in September to October. Stored substances are concentrated mainly in the root collar and the roots themselves. This phase should be finished in November, with the creation of a leaf rosette with 6 to 10 leafs, root collar with a diameter above 8 mm, leafs to 25 cm long, weight of the above ground biomass of 1.4–1.8 kg m^{-2}, large post-shaped root.

The transition into the generative phase occurs from the beginning of October. The plant requires at least 60–70 days of full vegetation. When the air temperature decreases under 5 °C (December to February), plants with a smaller number of leaves (less than four), are strongly susceptible to winter freezing injury. During this period, the length of the plants as well as leafs shrink by approx. 10%, the dry mass increases from approx. 12% to approx. 17%, the content of N in fibres decreases. Frosts reaching under –15 °C typically lead to the destruction of leaves, frosts lasting longer than 6 hours with temperatures under –18 to –20 °C usually destroy the leaf rosette. Weak or, on the contrary, oversized plants are devastated by frost under –13 to –15 °C. The winter period is unfavourable for the growth of above ground biomass. The roots are still growing in soil temperatures higher than 2 °C, in case of the Czech Republic this would represent most of winter. The developmental vegetation peak advances by about 2 stages.

When the soil temperature is above 2 °C, small white roots appear. The first dosage of N fertilizer is used (roots growth). This happens at the end of February – beginning of March. Mostly at the end of March when the air temperature is above 5 °C, the plants become green again.

This is immediately followed by the stem elongation growth (second dosage N). When the plant length is approx 20 cm, after the appearance of buds, the intensive stem elongation growth follows. This lasts about 14 days, ends when flowering begins, the plant creates about 50% of its above ground mass. It grows daily by about 5–8 cm, the content of all components, especially nitrogen, is diluted. During flowering, the plant loses all its stem leaves, but reaches 80% of its final weight. After the flowering phase, the volume of dry mass increases and although there is a loss of leaves, the yield of biomass increases by the growing pods (100% biomass). During the time of ripeness, the yield of dry biomass decreases by approx. 5% as well as the plants become smaller (Vašák et al., 1997).

The description of weather can be carried out in wide-ranging scope; from vague undefined terms such as 'dry', 'wet', 'warm', 'cold' to precisely defined characteristics of meteorological components. Even though these are usually very simple physical quantities, which can be described either quantitatively (eg air temperature or total precipitation) or qualitatively (eg presence of condensation, fog, storms or type of cloud) their cross determination is the decisive factor, which results in difficulties when assessing the respective years (Klabzuba and Kožnarová, 2000, 2002; Kožnarová and Klabzuba, 2002, 2003, 2004).

First of the aims of this paper is therefore the objectification of the input parameters, based on precise definitions of the terminology used. The second factor under consideration was the emphasis on high-risk and dangerous events during the cultivation of rape:

- Dry when preparing soil for sowing, while sowing and emergency (ie especially in August)
- Lack of precipitation resulting in reduction of plant quantity at the beginning of vegetation (August, September)
- High quantity of precipitation together with a very warm autumn (resulting in excessive biomass growth)
- Variation of relatively warm and cold periods in winter (December to March)
- Strong frost in winter (December to February) especially with no snow-cover preceded by a warm and wet autumn
- Dry conditions in spring at the beginning of vegetation
- Rainy and cold weather during flowering.

Methodology

Among the contemporary problems in the meteorological field applied in biological disciplines belongs the evaluation of weather throughout the cultivation year. The possibilities of modern measuring methods (dataloggers, automatic stations) make many producers do their own measurings. Large capacity of data-saving media, the possibility of time intervals when gathering data and the resulting immense quantity of information, often obtained in non-standard manner; result in very difficult interpretation of the findings and further usage of the data.

We have customized the selection of the specific objective meteorological, or climatologic characteristics to the above mentioned negative and high-risk events. The main criterion of our selection was availability of information – especially materials of the Czech Hydro-meteorological Institute. Therefore, the characteristics are commonly used and their definition, significance and possible interpretation have already been published (Klabzuba et al., 1999). The seven-level scale expressing the percentage of given inputs availability (Table 1) was used when processing the data.

Regarding the given topic we have selected only the conditions which can be considered as dangerous or of high-risk. They are indicated in chronological order:

- Dry, very dry and exceptionally dry months (August and September)
- Very wet or exceptionally wet months (August and September)
- Very warm or exceptionally warm months (October and November)
- Very cold or exceptionally cold months (December to February)
- High number of days with strong frost in winter months (December to February)
- Low number of days with snow-cover (December to February)
- High absolute temperature amplitude throughout cold 6 months (October to March)
- Dry, very dry or exceptionally dry spring months (April to June)
- High number of days with total precipitation larger than 1 mm (May and June).

We have created a three level diagram corresponding with Table 1 (Fig 1). The diagram presents the defined climatologic characteristics. Dangerous and high-risk factors are then classified in the following manner: event occurrence, high event occurrence and exceptionally high event occurrence. The diagram also allows us make visual assessment of the frequency of high-risk factor occurrence for each area, with regard to rape and rape-type plant cultivation.

Table 2 and Fig 2 illustrate the given events accumulation in respective rape years.

Table 1. Evaluation criteria

Normality evaluation	Quantile	Repetition probability	Temperature evaluation	Precipitation evaluation
Exceptionally above normal	<2.0%	less than once every 50 years	exceptionally warm	exceptionally wet
Significantly above normal	2.0 to 9.9%	less than once every 10 years	very warm	very wet
Above normal	10.0 to 24.9%	less than once every 4 years	warm	wet
Normal	25.0 to 75.0%	once every 2 years	normal	normal
Below normal	75.1 to 90.0%	less than once every 4 years	cold	dry
Significantly below normal	90.1 to 98.0%	less than once every 10 years	very cold	very dry
Exceptionally below normal	>98.0%	less than once every 50 years	exceptionally cold	exceptionally dry

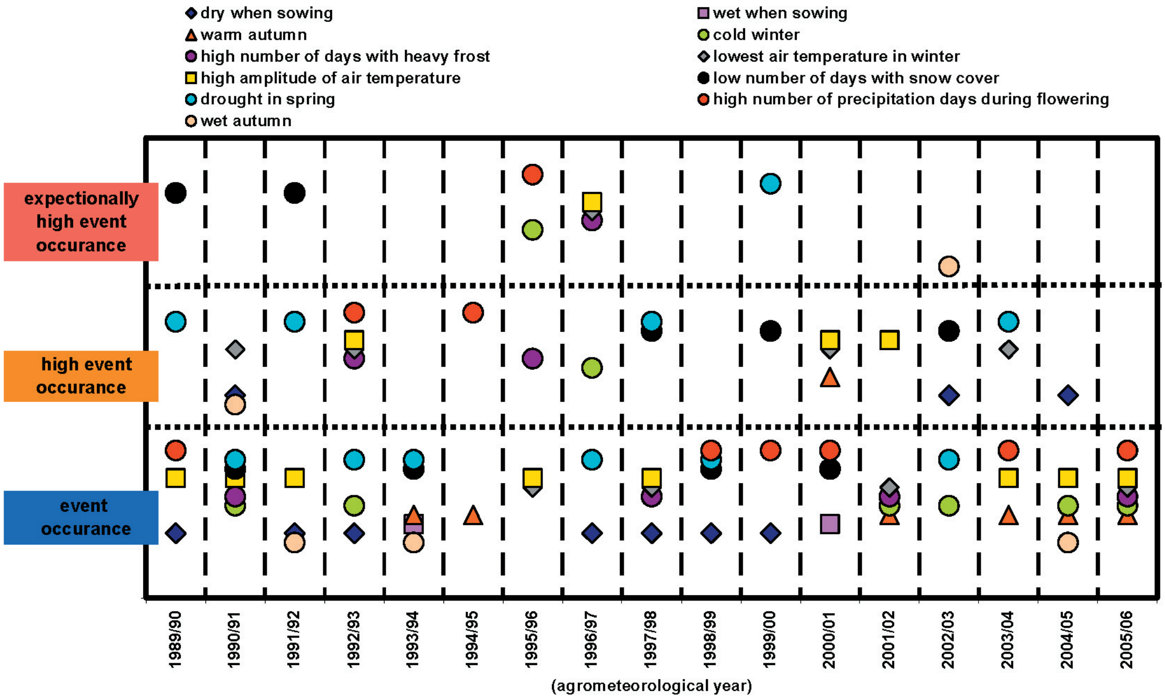

Fig 1. Evaluation of risk factors

Conclusions

The results gained, in accordance with the methodology presented, prove the commonly known fact, that the factors influencing the production or yields are always complicated and complex. The combinations of various negative and positive factors throughout the year affect the yields and their variability in each year. It is undisputable, that simple and multiple interactions may compensate the negative effect of individual factors or on the contrary, increase it. We are, however, convinced that the solution must be, on the basis of a wide debate, a selection of appropriate agro-meteorological characteristics, compatible with the databank of meteorological information, allowing for consistent processing method and a clear-cut interpretation of results. This should be followed by a study of interactions, using a longer time scale of data from specified cultivation areas, assessing validity of each parameter and resulting in a multiple factor statistical analysis in relation to yields.

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Table 2. Unfavorable and high-risk agro-meteorological events throughout 1989/90–2005/06

	Dry when sowing	Wet when sowing	Warm autumn	Cold winter	High number of days with heavy frost	Lowest air temperature in winter	High amplitude of air temperature	Low number of days with snow cover	Drought in spring	High number of precipitation days during flowering	Wet autumn
1989/90	+						+	+++	++	+	
1990/91	++			+	+	++	+	+	+		++
1991/92	+						+	+++	++		+
1992/93	+			+	++	++	++		+	++	
1993/94		+	+					+	+		+
1994/95			+							++	
1995/96				+++	++	+	+			+++	
1996/97	+			++	+++	+++	+++		+		
1997/98	+				+	+	+	++	++		
1998/99	+							+	+	+	
1999/00	+							++	+++	+	
2000/01		+	++			++	++	+		+	
2001/02			+	+	+	+	++				
2002/03	++			+				++	+		+++
2003/04			+			++	+		++	+	
2004/05	++		+	+			+				+
2005/06			+	+	+	+	+			+	

+ event occurrence; ++ high event occurrence; +++ exceptionally high event occurrence

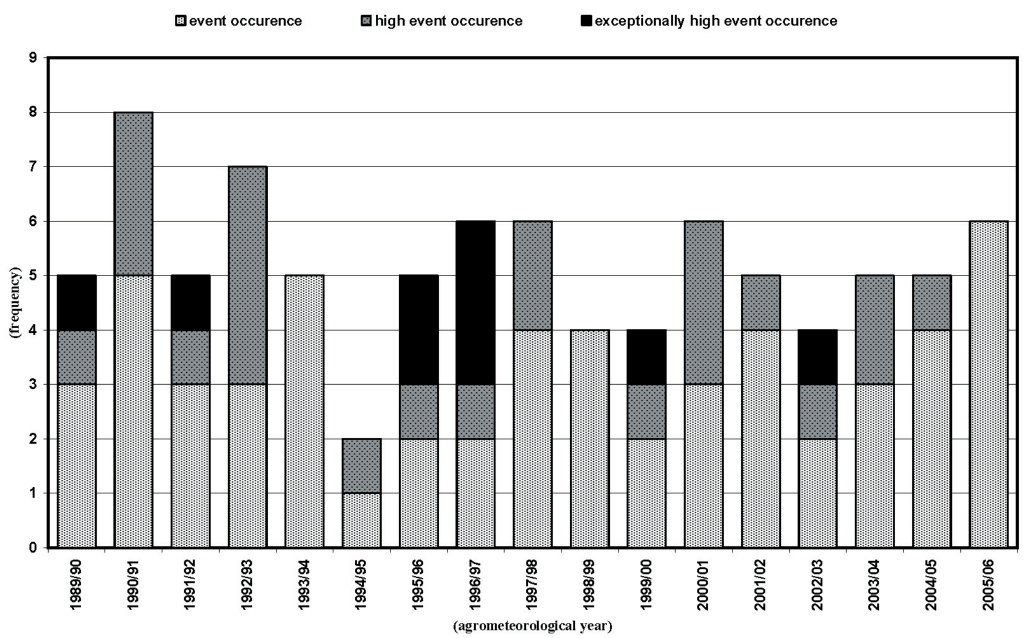

Fig 2. Frequency of dangerous and high-risk agro-meteorological events in three levels throughout 1989/90–2005/06

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Možnosti použitia štandardných klimatologických charakteristík pre agrometeorologické účely

Súhrn

Predkladaná práca sa zaoberá vytvorením modelu „optimálneho“ počasia pre pestovanie repky olejnej (*Brassica napus* L. var. *napus*). Východiskom bola parametrizácia negatívnych meteorologických podmienok ovplyvňujúcich rast, vývoj a výnos. Pomocou štandardných klimatologických charakteristík, semikvantitatívneho trojstupňového hodnotenia sme spracovali viac než pätnásťročné obdobie s dôrazom na nepriaznivé a rizikové meteorologické faktory (sucho či mokro pri siatí, teplá jeseň, chladná zima, veľký počet dní so silným mrazom, malý počet dní so snehovou pokrývkou, veľký počet dní so zrážkami v období kvetu). Výstupom je jednoduchý grafický model, ktorý umožňuje vyjadriť kumuláciu účinkov negatívnych faktorov v priebehu vegetačného obdobia.

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Methodological paper

Methodological overview to hemispherical photography, demonstrated on an example of the software GLA

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Abstract

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

This contribution provides a literature overview concerning minimising the two main error sources at shooting and evaluating hemispherical photographs with the aid of the software Gap Light Analyser 2.0. It deals with materialisation of the process in which these phenomena arise. The point is at determining the exposure time and thresholding (determining the optimum brightness value for the pixel as the threshold for distinguishing between the foliage and the sky patches on a hemispherical photograph).

Keywords

hemispherical photography, Gap Light Analyser, SideLook, thresholding, exposure time

Introduction

Assessment of light conditions in forest stands results in important information about growth conditions for the plants (both woody plants and herbs) in the understorey. Even small changes in structure of an almost compact crown layer can result in pronounced changes not only in amount of the penetrating sun radiation but also to the site microclimate regime, which has an important influence on growth and survival of the involved plant species (Whitmore et al., 1993; Brown, 1993, 2000; Hale and Brown, 2005).

Quantitative evaluation of light regime in forest environment by direct measurement is both time and money consuming, due to considerable time and spatial variability of this environmental factor. For this reason, there have been developed numerous indirect methods targeting at determining of amount of accessible sun radiation, based on assessment of the crown layer structure of the stand. One of them is the method providing with evaluation of photographs made at 180° "fisheye" lenses (Jennings et al., 1999). A hemispherical photograph (Fig 1) maps the size, magnitude and distribution of gaps in the crown layer in relation to the spot at which the photograph was taken (Jelaska et al., 2006). The result is that, apart from indirect assessment of under-canopy light environment, the method can also be used for assessing characteristics of the crown layer's structure (canopy openness, effective leaf area index). The first hemispherical objective was manufactured by Hill (1924 in Jelaska et al., 2006) with the purpose to study cloudiness. In the biological research, the approach was used for the first time by Evans and Coombe (1959 in Jelaska et al., 2006). The fundamental of the method is in thresholding – selection (finding) an optimum brightness value for the imaging point (pixel) as the threshold for distinguishing between the vegetation and sky patches (Jonckheere et al., 2004).

Fig 1. Hemisperical image

Recently, there have been developed numerous commercial software packages, as well as freeware programmes that were consequently used in a broad range of applications: Winscanopy (Regent Instruments, Quebec, Canada), Solarcalc, Winphot (Steege, 1997), HemiView (Delta-T Device, Cambridge, UK), Gap Light Analyser (Frazer et al., 1997) and CIMES (Walter et al., 2003) (all in Jonckheere et al., 2005).

The aim of this contribution is to inform the reader about the possible use of this method for indirect assessment of light conditions in the stand. We present a literature review of the published data on use (taking and processing) of hemispherical photographs, illustrated with an example of the freeware programme Gap Light Analyser (GLA), version 2.0 (Frazer et al., 1999).

Gap Light Analyser

This software transforms the colours from the photos to black and white, in order to quantify the pixels before calculation of canopy openness. The programme is freely downloadable from the site http://www.rem.sfu.ca/forestry/index.htm.

The programme has already been used by several authors: Shine et al. (2002), Simoni et al. (2003); Schnitzler and Closset (2003); Jelaska (2004); Morsdorf (2006); Janišová et al. (2007); Glončák (2007); Crane and Shearer (2007); Dauzat et al. (2008); Montero et al. (2008) and others.

Tresholding and its objectivization

The most considerable drawback of this software package is that it performs based on a manually, interactively determined, virtually chosen threshold value for the entire picture – which is, according to Englund et al. (2005) an indisputable source of controversies, con-tradictions and errors with the variance dependent on the measuring subject. The sensitivity of this programme to the variable threshold value was evaluated by Hardy et al. (2004) (on example of total solar transmissivity). They tested the sensitivity of the predicted transmission value based on close-to-realistic high and low threshold values, each affecting the predicted transmissivity by about 10%. This drawback can be (the authors seek) eliminated in various ways – by using blue channel, proved to be the best for separation of the pixels into the sky and non-sky classes (Jelaska et al., 2006, also noted by Frazer et al., 1999; Zhang et al., 2005), by using pixel histograms (chosen is the value with the lowest abundance) with following visual control (Barthod and Epron, 2005), by direct measuring transmissivity and subsequent determining the equivalent transmissivity value in GLA, together with its associated threshold value (Hardy et al., 2004), by evaluating all the images by the same person (Beaudet and Messier, 2002), or three independent persons subsequently determining the mean threshold value (Ramos and Santos, 2006). The manual thresholding is also much time consuming, and, consequently, not suitable for implementation in processing of large numbers of photographs (Koller et al., 1994 in Jonckheere et al., 2005).

Objective, reproducible, comprehensible and to a large number of images easy-to-implement method for defining the threshold value has been developed and into the shareware programme SideLook ver. 1.1 (Nobis 2005) embedded by Nobis and Hunziker (2005). The authors show that the automatic threshold algorithm for separating canopy and sky by edge detection is appropriate to replace the widely used manual interactive processing. It also improves the accuracy of results, especially in comparison with single manual thresholding. These conclusions were also confirmed by Monte et al. (2007).

Exposure time

Another possible and important source of errors is exposure (exposure time; Rich, 1988, 1993 in Jonckheere et al., 2004). The results of Zhang et al. (2005) demonstrate that digital hemispherical photographs taken with automatic exposure are not reliable, because they cause effective leaf area index underestimations for medium and high density canopies and corresponding gap fraction overestimations. While in case of open canopies the opposite holds. Beaudet and Messier (2002) and Glončák (personal communication) ensure sufficient contrast between the sky and foliage thanks to bracketing the exposure time indicated by a built-in light meter, or resulting from under-exposing the photographs, respectively. Zhang et al. (2005) have determined the optimum exposure time and developed a protocol for acquiring digital hemispherical photographs. The protocol requires first measuring reference exposure for the open sky with using a built-in camera light meter, and then taking photographs inside the canopy with using the same camera with two stops of more exposure than the reference exposure in order to make the sky appear white and consequently also maximize the contrast between the sky and foliage. For example, if the sky reference is F5.3 (aperture) and shutter speed is 1/1000 s, the correct exposure inside the stand is F5.3 and shutter speed 1/250 s.

Conclusion

In spite of all limitations associated with this indirect method for assessment of forest canopies and understorey illumination (Roxburgh and Kelly, 1995; Jennings et al., 1999), the hemispherical photography provides an important and useful tool in ecological studies. Unification and objectivization of methodical techniques at shooting and evaluating hemispherical photographs is important in term of improvement of outputs accuracy and at comparasion outcomes from different sources too.

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Metodologický prehľad k hemisferickej fotografickej technike na príklade počítačového softvéru GLA

Súhrn

Príspevok uvádza literárne poznatky o minimalizovaní dvoch hlavných zdrojov chýb pri zachytávaní a vyhodnocovaní hemisférických snímok využitím počítačového softvéru Gap Light Analyser 2.0, respektíve o zobjektivizovaní procesu, pri ktorom vznikajú. Jedná sa o určenie expozičného času a „tresholding" (stanovení optimálnej hodnoty jasu obrazového bodu – pixelu ako hranice za účelom odlíšenia olistenia od častí oblohy na hemisférickej fotografii). Objektívny spôsob určenia hodnoty „treshold" ponúka program SideLook 1.1. Za najvhodnejší spôsob na určenie hodnoty expozičného času, ktorá maximalizuje kontrast medzi oblohou a olistením je jeho zvýšenie oproti hodnote zmeranej z nezakrytej oblohy o dva kroky (pri nezmenenej hodnote clony).

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