Influence of stand density on Zn and Cu concentrations in beech leaves

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ABSTRACT: The paper deals with the response of leaves in a beech stand to opening after shelterwood cutting of various intensity (stocking of 0.3, 0.5, 0.7, 0.9) performed in 1989. The research was running in 1996–1997, on dominant, codominant and subdominant sample trees representing the mean stand diameter on all the examined plots. The obtained data were compared separately for the leaves from the upper, medium and lower crown thirds. In some cases, there has been confirmed statistically significant influence of the cutting strength and other studied factors on Zn and Cu concentrations – at a significance level of $\alpha = 0.05$. We found significant influence on the concentrations of the analysed elements, their total amounts (depending on the relevant amounts of leaves on the plots) and their amounts in leaves of unit trees. This paper is a continuation of the previous work focussed on Mn and Fe concentrations in beech leaves.

Keywords: *Fagus sylvatica* L.; leaf; concentration; zinc; copper; shelterwood cutting

Shelterwood cutting, a method commonly used in forest management practice, results (Marušák 2001) in providing favourable ecological conditions for successful forest management (Sedmák, Hladík 2002). More details about this practice and the changes in leaf structure and morphology can be found in our previous paper (Machava, Barna 2005).

Zinc is generally considered a highly mobile element in plants; however, some authors do not support this common opinion. All depends on the quantity of available Zn. Soluble forms are easily available to plants. The uptake of Zn by plants is controlled by its content in soil solution.

The physiology and biochemistry of adverse effects of Zn on plants are similar to other micronutrients, but Zn is not so toxic. Its optimal concentrations in forest tree species range between 15 and 80 mg/kg (Bublinec 1994), these values correspond to the lowest acceptable concentration of 19 mg/kg quoted by Materna (1963) for trees. Zinc is an essential element and Zn deficiency manifests itself through chlorosis of assimilatory organs, local necrosis, essentially smaller leaf surface, premature leaf cast and suppressed growth and fertility of trees. The typical symptom of Zn deficiency is chlorotic leaves, turning bronze-coloured and gradually withering. The metabolic dysfunction is caused not only by deficiency of this element but also by its surplus. The typical symptoms of increased Zn concentrations in trees are, for example, chlorotic and necrotic ends of leaves, intervenous chlorosis and atrophic and twisted roots (Kabata-Pendias, Pendias 1992).

Compared to the other elements, copper exhibits a low mobility in plants. The major part of this element is supposed to be accumulated in roots or leaf tissues. Only a small part of Cu is transported to young vegetative organs. The distribution of Cu amount in plant is very variable, with the lower mean value compared to Zn. Usually it is around 10 mg/kg (Bojarczuk et al. 2002). The analysed concentrations are evaluated in connection with allowable

concentrations of 2–14 mg/kg (Bublinec 1994). The highest concentrations were recorded in shoots and are associated with individual phases of growth.

The main goal of this paper is to discuss the trends of Cu and Zn concentrations in beech leaves induced by changed ecological conditions after shelterwood cutting of different intensities. Research was conducted across the whole tree crown. Tree social status in the stand and leaf position in the tree crown (the upper, middle and lower thirds) were taken into account.

MATERIALS AND METHODS

Study area

Research was conducted at the Ecological Experimental Station (EES) Kremnické vrchy Mts., the Western Carpathians, Central Slovakia (48°38´N, 19°04´E). The studied stand is 100 years old (at the sampling time) and it is situated on a westward oriented slope with the gradient up to 20°, at an altitude of 450–470 m above sea level. The mean annual temperature is 8.2°C, in the vegetation period 14.9°C, the mean annual precipitation total is 664 mm, in the vegetation period 370 mm. The main stand-forming association is *Dentario bubliferae-Fagetum*, with locally admixed *Carici pilosae-Fagetum*, from the aspect of forest typology it is *Fagetum pauper inferior* – type 3312 (Kukla et al. 1998).

Prior to this research, the stand was managed according to the common forestry practice. Beech (80–95%) is a dominant tree species in the locality while fir, oak and hornbeam are admixed species.

The influence of shelterwood cutting of different intensities on Cu and Zn concentrations in leaves was investigated on four subplots of the EES. After regeneration cutting in 1989, the original stand density 0.9 was changed to the following values: to 0.3 on plot H (high intensity cutting), to 0.5 on plot M (medium intensity cutting), to 0.7 on plot L (low intensity cutting). Plot C (control) remained intact

with the original stand density of 0.9. Barna (2000) described the trends of mensurational variables on the particular plots after the cutting (1989); these data were compared with the corresponding data from 1996 (sampling). Other characteristics of the locality and research on the plots can be found in previously published papers (Pichler, Gregor 1994; Kellerová 2001; Kodrík 2002).

The evaluation of the influence of shelterwood cutting intensity on plot parameters is based on an assumption that all plots have similar properties, including Cu and Zn amounts in soil.

Plant material

Leaf position in the tree crown was the first criterion for leaf sampling when the chemical composition of beech leaves was examined. Consequently, leaves were sampled from the upper, middle and lower thirds of tree crowns. Tree social status in the stand classified according to Kraft (dominant – with soundly developed and strong crowns; codominant – with well developed crowns, forming the general layer of canopy; subdominant – with irregularly developed crowns, suppressed from one or several sides) was the second criterion. The two criteria provided a base for the complex evaluation of changes in concentrations of the examined elements as a response to altered ecological conditions in the examined stands. Further differentiated in three sub-groups corresponding to the tree social status was also done. That means that the sample trees were established in 4 stands with different intensities of shelterwood cutting (the third criterion with degrees of cutting – intensive, middle, low and control – without cut), in each of them a dominant, subdominant and codominant tree was selected. Consequently, the total number of sample trees was 12 (Barna 2001). Sample tree harvesting began after they had achieved physiological maturity of leaves (23 July–10 September 1996, 1997).
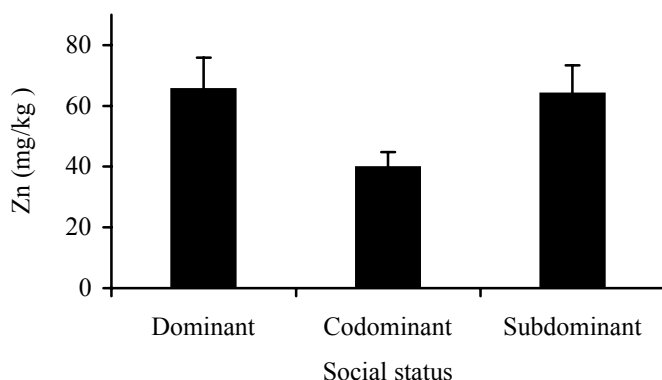

Fig. 1. Zn concentrations according to the tree social status. Different letters indicate significant differences between the means; Duncan's test applied (P ≤ 0.05). Standard deviations are marked as a segment on the bars

Table 1. ANOVA analysis of the influence of the social status of trees in stand (dominant, codominant, subdominant), crown layers (leaf position within the crown: upper, middle and lower thirds of the living crown height) and stand density on plots (C, L, M, H): **A**. Zn concentrations; **B**. Cu concentrations

Character	Source of variation	d.f.		
A. Zn	social status	2	33.948	< 0.0001
	crown layers	2	0.009	0.9909
	stand density*	3	0.229	0.8759
B. Cu	social status	2	32.084	< 0.0001
	crown layers	2	0.184	0.8329
	stand density*	3	0.195	0.8990

Error d.f. = 33 (*32)

After drying, leaf samples were homogenised. The sample amounts of 0.5 g were treated with concentrated HNO_3, heated in a microwave furnace, filtered and adjusted to a volume of 50 ml. Element concentrations in the solution were determined by Atomic Absorption Spectroscopy (AAS) on GBC Avanta 900 spectrometer. A more detailed procedure for the evaluation of the amounts of micronutrients Mn and Fe in beech leaves can be found in MACHAVA and BARNA (2005) and for the macronutrients Ca, Mg, K and Na see BARNA and BUBLINEC (2002).

RESULTS AND DISCUSSION

Concentrations of Zn and Cu in leaves of the analysed beech trees varied according to the tree social status and the leaf position in the tree crown. The highest Zn concentration (87.05 mg/kg) was found in the upper part of the dominant tree on plot C and the lowest value (32.81 mg/kg) in the middle part of the codominant tree on plot M. At first, Zn concentrations will be evaluated on the particular plots according to stand density.

Zn concentrations in all crown thirds in dominant, codominant and subdominant trees on plots C, L and M had the same tendency – they decreased from dominant to subdominant and codominant class. The exception was the middle part on plot C, where the highest concentrations were recorded in the subdominant trees, which is in accordance with the trend of Zn concentrations on plot H. The highest Zn contents were in the dominant trees on plots C, L, M (79.95, 68.21 and 87.05 mg/kg) and in the subdominant tree on plot H (82.69 mg/kg). The lowest values were in the codominant sample trees 38.23, 32.81, 39.60 and 35.06 mg/kg. This difference tested by ANOVA was significant at $P < 0.00001$ (Fig. 1, Table 1). Low values in codominant trees were probably caused by the fact that this sampling was carried out in 1996, while the others in the next year 1997. Quality and quantity of precipitation are dominant climatic factors influencing concentrations of the examined elements (PICHLER 1994). The total precipitation in the vegetation season (April–September) 1997 amounted to only 61% of that in 1996. After the rainfall had passed through the crown canopy, the highest element deposition on the monitoring plots was found in spring months (DUBOVÁ, BUBLINEC 1998). Since in 1996 there was no flushing until April (SCHIEBER, KOVÁČOVÁ 2002), the difference of

Table 2. Statistical characteristics of Zn and Cu concentrations (mg/kg) of beech foliage on plots with different initial stand density (H – 0.3, M – 0.5, L – 0.7, C – 0.9)

Characteristics	Zn				Cu			
	H – 0.3	M – 0.5	L – 0.7	C – 0.9	H – 0.3	M – 0.5	L – 0.7	C – 0.9
Mean value	59.22	57.36	55.30	53.69	7.54	6.85	6.57	7.48
Error of mean value	5.31	5.50	3.71	5.43	1.40	1.26	0.32	0.99
Standard deviation	15.93	16.50	11.13	16.28	4.20	3.78	0.95	2.98
Coefficient of variation (s_d%)	26.90	28.76	20.13	30.33	55.70	55.27	14.38	39.79
Kurtosis	–1.21	–0.74	–1.52	1.18	–0.56	1.39	–0.20	0.03
Skewness	0.25	–0.35	–0.58	0.86	1.04	1.33	0.56	1.24
Minimum	38.23	32.81	39.60	35.06	4.00	2.65	5.50	4.93
Maximum	82.69	79.95	68.21	87.05	15.17	14.77	8.34	12.48
Confidence level (95.0%)	12.24	12.68	8.56	12.52	3.23	2.91	0.73	2.29
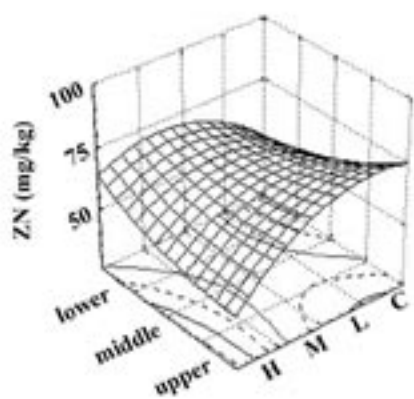
(a) Dominant trees
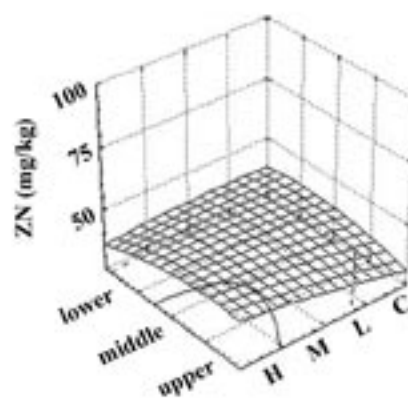
(b) Condominant trees
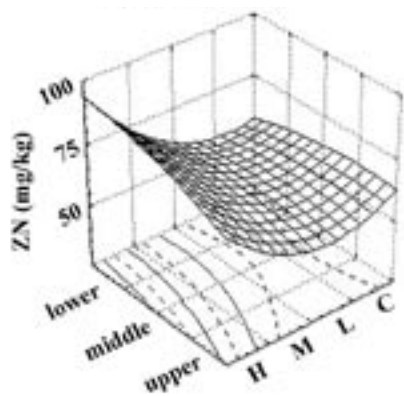
(c) Subdominant trees

Figs. 2a–c. Course of Zn concentrations in beech leaves for dominant (a), codominant (b), and subdominant trees (c) according to cutting intensity (for plots H, M, L, C) and crown part (upper, middle, and lower third)

255 mm between the April and May precipitation was even more conspicuous compared to the value of 75 mm in 1997. Although the influence of sampling year on Zn concentration was considerable ($P < 0.00001$), when included into ANOVA covariates, it did not cause any significant differences at relevant significance levels (Table 1). Also in Cu (Table 1), the lowest concentrations were found in codominant trees ($P < 0.00001$). The influence of the sampling year on Cu concentrations is also significant ($P = 0.00607$). The results of ANOVA (Table 1) show that the leaf position in the tree crown does not exert any significant influence on Zn concentrations.

The largest difference in concentrations between the crown thirds was recorded in the dominant trees (16.44 mg/kg), in the codominant and subdominant trees these differences were smaller and did not differ very much from each other (8.19 and 9.51 mg/kg). Mean Zn concentrations on the examined plots (Table 2) correlate with cutting intensity, increasing from 53.69 on plot C to 59.22 mg/kg on plot H, however this difference is not significant due to a high variation (Table 1).

The highest Cu content (15.17 mg/kg) was recorded in the middle part of the subdominant tree on plot H and the lowest value (2.65 mg/kg) in the middle part of the codominant tree on plot M. Unlike zinc, in which all the lowest concentrations were found in all thirds of codominant trees, all the highest concentrations of Cu were found in all thirds of

Table 3. Zn concentrations in beech foliage on plots with different stand density (H, M, L, C see Table 1) and total leaf dry mass from samples

Plot – initial stand density	Dominant trees		Codominant trees		Subdominant trees	
	Zn (mg/kg)	leaves (kg)	Zn (mg/kg)	leaves (kg)	Zn (mg/kg)	leaves (kg)
H – 0.3	57.79	16.34	42.31	9.55	77.56	7.21
M – 0.5	72.18	21.43	38.57	10.50	61.32	3.13
L – 0.7	65.23	12.78	41.30	8.44	59.44	2.23
C – 0.9	66.85	14.28	36.60	4.79	57.61	1.44
Mean	65.51 ± 5.95	16.21 ± 3.78	39.70 ± 2.60	8.32 ± 2.50	63.98 ± 9.18	3.50 ± 2.57

Table 4. Zn content (mg) in foliage from one beech and unit beech (according to the social status) in stand of different density

Plot – initial stand density	Dominant		Codominant		Subdominant	
	tree	unit tree[1]	tree	unit tree	tree	unit tree
H – 0.3	944.24	283.27	404.03	121.21	559.21	167.76
M – 0.5	1,546.86	773.43	405.03	202.52	191.93	95.97
L – 0.7	833.58	583.51	348.61	244.03	132.54	92.78
C – 0.9	954.65	859.19	175.31	157.78	82.96	74.66

[1]Zn content in unit tree leaves represents approximately Zn quantity in leaves at full density

subdominant trees. Similarly to zinc, the lowest Cu contents were mostly in codominant trees but for Cu no significant difference between the mean values in codominant and dominant trees was recorded ($\alpha = 0.05$). The influence of the leaf position in the crown on Cu concentrations was not significant – like in Zn (Table 1). The distribution of mean values in the crown thirds increased from dominant to subdominant trees on all plots. The mean Cu concentrations on some plots were independent of the stand density (Tables 1 and 2), the difference between them was not significant ($\alpha = 0.05$).

The relationships between the stand density, Zn concentrations and leaf dry mass were investigated and some of them were found significant: the relation between cutting intensity and Zn concentrations in leaves of **subdominant** trees (equation 1) and between Zn concentrations in leaves and dry mass of assimilatory organs (DAOM) (equation 2). Zn concentrations in leaves increased with the simultaneous increase of cutting intensity from plot C to H (Table 3). The same tendency was found in DAOM (MACHAVA, BARNA 2005). Relations between the Zn concentrations and cutting intensity were not significant in **dominant** and **codominant** trees. Finally, relations between cutting intensity and Zn amounts in the foliage of the sample tree and a unit tree were analysed (Table 4). The unit tree has such parameters that are typical of a tree under full stand density. For example, we have two plots of the same area. On the first plot there are 3 trees and on the second one 9 trees. These two groups of trees grow under different conditions – an amount of light and nutrients, etc. The parameters of the unit tree in the first case are computed multiplying the determined values of variables for a given tree by 3/10 and in the second by 9/10. It means that in the first case the values of the analysed variables are lower compared to the second case.

$$y = 82.495 - 30.784 \times SD; \qquad r = -0.869 \qquad (1)$$

where: SD – stand density

$$y = 51.525 + 3.556 \times SD; \qquad r = 0.9943 \qquad (2)$$

Significant relationships ($\alpha = 0.05$) were found in codominant and subdominant trees for Zn amount in foliage of the sample trees (3, 4) and in subdominant trees in foliage of unit trees (5). Although the amounts in foliage of subdominant trees on the examined plots were multiplied by different coefficients, the correlation coefficients for both linear regressions (4, 5) had the same value of –0.888.

$$y = 556.019 - 371.29 \times SD; \qquad r = -0.883 \qquad (3)$$

$$y = 688.102 - 744.07 \times SD; \qquad r = -0.888 \qquad (4)$$

$$y = 192.5377 - 141.242 \times SD; \qquad r = -0.888 \qquad (5)$$

Cu concentrations in leaves of dominant, codominant and subdominant trees on the examined plots (from C to H) show quite different tendencies. While in dominant trees the highest Cu content (5.58 mg/kg) was found on plot C and the lowest (5.11 mg/kg) on plot H with the highest cutting intensity, the tendency in subdominant trees was nearly opposite.

The lowest Cu level (7.50 mg/kg) is on plot L with the lowest cutting intensity, the highest Cu content (12.87 mg/kg) is on plot H. However, the Cu concentration on plot C did not follow the trend.

The relationships between the cutting intensity and Cu concentrations in leaves were investigated and some of them were found significant ($\alpha = 0.05$). This applies to dominant (6) and subdominant trees (7). But in the second case it was true only of plots L to H. The relationship between the Cu concentration in leaves and DAOM (Table 5) was significant in subdominant trees (8), but again only over the plots L to H.

$$y = 4.7862 + 1.2485 \times SD; \qquad r = 0.9857 \qquad (6)$$

$$y = 17.2508 - 3.4475 \times SD; \qquad r = -0.9765 \qquad (7)$$

$$y = -4.3482 + 0.8111 \times SD; \qquad r = 0.8417 \qquad (8)$$

Similarly to Zn, Cu amounts in beech leaves were influenced by cutting intensity (*SD*). This relationship was significant in subdominant trees in the sample tree leaves (9), where the lowest amount (15.78 mg) was found on plot C and the highest value (92.82 mg) on plot H (Table 6), and in the unit tree

Table 5. Cu concentrations in beech foliage on plots with different stand density (for plots H, M, L, C) and total leaf dry mass from samples

Plot – initial stand density	Dominant trees		Codominant trees		Subdominant trees	
	Cu (mg/kg)	leaves (kg)	Cu (mg/kg)	leaves (kg)	Cu (mg/kg)	leaves (kg)
H – 0.3	5.11	16.34	4.64	9.55	12.87	7.21
M – 0.5	5.49	21.43	3.85	10.50	11.21	3.13
L – 0.7	5.67	12.78	6.56	8.44	7.50	2.23
C – 0.9	5.88	14.28	5.60	4.79	10.96	1.44
Mean	5.54 ± 0.33	16.21 ± 3.78	5.16 ± 1.18	8.32 ± 2.50	10.63 ± 2.26	3.50 ± 2.57

leaves (10) and in dominant trees in the unit tree leaves (11). The correlation coefficients for these two linear regressions in subdominant trees have nearly identical values to those found in zinc.

$$y = 114.95 - 124.75 \times SD; r = -0.8885 \qquad (9)$$

$$y = 31.4615 + 23.40 \times SD; r = -0.8507 \qquad (10)$$

$$y = 9.4615 + 71.7655 \times SD; r = 0.8803 \qquad (11)$$

The determined concentrations were statistically evaluated (Table 2) and can be expressed by some statistical characteristics, such as arithmetic mean, standard deviation, coefficient of variation, etc.

Comparing the mean Zn concentrations on the examined plots according to the tree social status, the highest value was determined in the dominant trees on plots C, L and M; an increasing tendency was found from codominant to subdominant and dominant trees. Only on plot H with the highest cutting intensity, this tendency began with codominant to dominant and finished with subdominant tree. Kurtosis indicates the measure of asymmetry of the examined distribution in comparison with normal distribution. Skewness expresses the degree of the distribution variability around the mean value. Because all these values are within an interval of (–2, +2), the distribution of the sampled population does not differ from the normal one (test of normality – SPSS programme).

Fig. 2 shows a 3-dimensional representation of Zn concentrations. The course of these concentrations is well fitted by an appropriate function, however, the real trend can be a little different. The highest concentrations in dominant trees were recorded on

plot M and the lowest ones on plot H, in codominant trees the highest contents were on plot H and the lowest ones on plot C; however the concentrations on plot L were outside this range. In subdominant trees, the highest and lowest values were on the same plots as in the codominant trees, but concentrations gradually descended from plot H to C.

Comparing the mean Cu concentrations on the examined plots according to the tree social status, the highest value was found in subdominant trees on all plots, while an increasing tendency was evident from codominant to dominant and subdominant trees, only on plot L it was from dominant to codominant and finishing with subdominant trees. The values of kurtosis and skewness coefficients are within an interval of (–2; 2), it means that the distribution of the sampled population does not differ from the normal one.

Fig. 3 shows the 3-dimensional representation of Cu concentrations. The highest Cu concentrations in dominant trees cannot be distinguished because concentration differences varied within a narrow range (1.77 mg/kg). A similar situation was in co-dominant trees, but differences between concentrations were higher (2.72 mg/kg). In subdominant trees the highest contents were on plot H and the lowest ones on plot L. The Cu concentrations on plot C were higher compared to those on plot L.

The mean concentrations of Cu and Zn in beech leaves did not exceed the ranges of allowable concentrations 2–14 mg/kg and 15–80 mg/kg, respectively (BUBLINEC 1994). Similar concentrations were reported by MACHAVA (2002), who examined the

Table 6. Cu content (mg) in foliage from one beech and unit beech (according to the social status) in stand of different density

| Plot – initial stand density	Dominant		Codominant		Subdominant	
	tree	unit tree[1]	tree	unit tree	tree	unit tree
H – 0.3	83.480	25.044	44.26	13.278	92.82	27.85
M – 0.5	117.540	58.770	40.37	20.185	35.09	17.55
L – 0.7	72.410	50.687	55.37	38.759	16.71	11.70
C – 0.9	83.980	75.582	26.84	24.156	15.78	14.20

[1]Cu content in unit tree leaves represents approximately Cu quantity in leaves at full density
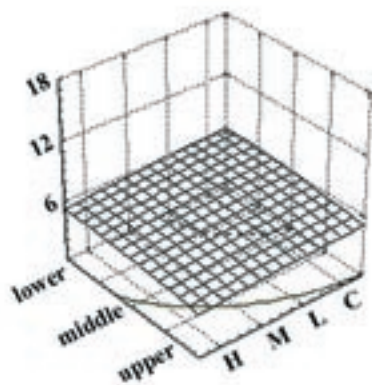
(a) Dominant trees
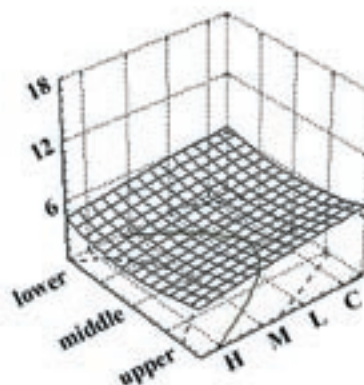
(b) Condominant trees
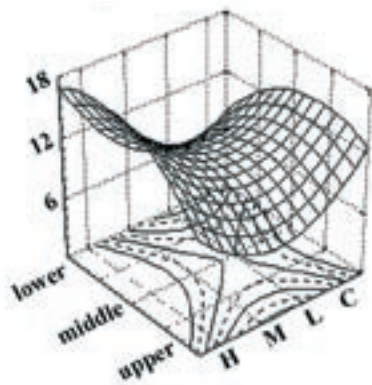
(c) Subdominant trees

Figs. 3a–c. Course of Cu concentrations in beech leaves for dominant (a), codominant (b) and subdominant trees (c) according to cutting intensity (for plots H, M, L, C) and crown part (upper, middle, and lower third)

dependence of micronutrient concentrations on the leaf position on twigs. The highest mean Cu concentration of 14.6 mg/kg was in the second leaf on twigs. Determined Zn concentrations were closely below the highest allowable value. The highest recorded concentration was 60.5 mg/kg.

CONCLUSION

Shelterwood cutting of specified intensity applied on the particular plots resulted in different ecological conditions for the growth of trees. These different local conditions were reflected not only in different shapes and structure of leaves but also in concentrations of Zn and Cu. The amount of light and the amount of available forms of Zn and Cu were the two most important factors influencing the uptake of these micronutrients by the trees.

Zn concentrations on the particular plots were usually the highest in dominant trees in the lower third of the crown (plots L and M), except for plot C where the highest concentration was in general in the upper part. On plot H, the highest value was also in the lower crown third, but in subdominant trees. The lowest contents of Zn on the examined plots were found always in codominant trees. It suggests that the highest concentrations can be connected with the sunlit leaves.

Cu concentrations on the examined plots were the highest in subdominant trees in the crown middle thirds, except for plot L where it was in the lower third, but in this case all concentration values were similar. It means that the highest Cu concentrations are usually connected with a reduced amount of light and with the middle third of the crown. The lowest ones were recorded either in codominant trees in their middle or lower crown thirds or in dominant trees in their upper crown parts.

The relationships between the stand density, determined concentrations and leaf dry mass were analysed and some of them were found significant. In zinc, it is primarily the relation between the stand density and Zn concentrations in leaves (equation 1) and between Zn concentrations in leaves and DMAO (eq. 2) in subdominant trees. It also applied to the relation between the cutting intensity and Zn amount in the sample tree foliage in codominant and subdominant trees (eq. 3, 4) and in unit beech foliage in subdominant trees (eq. 5). Relationships between shelterwood cutting intensity and Cu concentrations in leaves were significant in dominant and subdominant trees (eq. 6, 7). The relationship between Cu concentration in leaves and DMAO was significant in subdominant trees (eq. 8). The relation between cutting intensity and Cu amount in the sample tree foliage was significant in subdominant

trees (eq. 9) and in unit subdominant and dominant trees (eq. 10, 11).

These relationships have shown that the concentrations and amounts of Cu and Zn in beech leaves are controlled by local ecological conditions, mainly by the amount of available light. They were found significant mainly in subdominant trees, which grow in shadow positions. Our results were obtained with a limited number of sample trees (12); a larger sample set would be required to draw a fully reliable generalisation conclusion.

References

BARNA M., 2000. Impact of shelterwood cutting on twig growth in predominant beech trees (*Fagus sylvatica* L.). Ekológia (Bratislava), *19*: 341–353.

BARNA M., 2001. Production of biomass of beech (*Fagus sylvatica* L.) leaves and buds after cutting of various intensity. Journal of Forest Science, *47*: 164–173.

BARNA M., BUBLINEC E., 2002. Mineral macronutrients in beech canopy foliage in a stand with different densities. Ekológia (Bratislava), *21*, Suppl. 2/2002: 109–117.

BOJARCZUK K., KAROLEWSKI P., OLEKSYN J., KIELISZEWSKA-ROKICKA B., ŽYTKOWIAK R., TJOELKER M.G., 2002. Effect of polluted soil and fertilisation on growth and physiology of Silver birch (*Betula pendula* Roth.) seedlings. Polish Journal of Environmental Studies, *11*: 483–492.

BUBLINEC E., 1994. Koncentrácia, akumulácia a kolobeh prvkov v bukovom a smrekovom ekosystéme. Acta Dendrobiologica, Ústav ekológie lesa SAV: 132.

DUBOVÁ M., BUBLINEC E., 1998. Chemizmus zrážok v Karpatskom bukovom ekosystéme. Folia Oecologica, *24*: 113–119.

KABATA-PENDIAS A., PENDIAS H., 1992. Trace Elements in Soils and Plants. London, CRC Press, 2nd edition: 365.

KELLEROVÁ D., 2001. Changes in air pollution in the areas of the National Park Malá Fatra and EES Kremnické vrchy Mts. Folia Oecologica, *28*: 95–100.

KODRÍK M., 2002. Annual litter fall dynamics of a beech forest ten years after regeneration intervention. Ekológia (Bratislava), *21*, Suppl. 2/2002: 110–116.

KUKLA J., KONTRIŠ J., KONTRIŠOVÁ O., GREGOR J., MIHÁLIK A., 1998. Causes of floristical differentiation of *Dentario bulbiferae-Fagetum* (ZLATNÍK 1935; HARTMANN 1953) and *Carici pilosae-Fagetum* Oberd. 1957 associations. Ekológia (Bratislava), *17*: 177–186.

MACHAVA J., 2002. Vplyv zvýšených koncentrácií ťažkých kovov na zdravotný stav smreka a buka v modelových podmienkach a prírodnom prostredí. [Doktorandská dizertačná práca.] Zvolen, TU: 159.

MACHAVA J., BARNA M., 2005. The influence of stand density on Mn and Fe concentrations in beech leaves. Journal of Forest Science, *51*: 225–236.

MARUŠÁK R., 2001. Possibilities of using of allowable cut indicators in shelterwood system. In: GADOW K., NAGEL J., SABOROVSKI J. (eds.), Continuous Cover Forestry. International IUFRO Conference, Göttingen: 195–202.

MATERNA J., 1963. Výživa a hnojení lesních porostů. Praha, SZN: 227.

PICHLER V., 1994. Die Anwendung von Geostatischen Methoden in Untersuchung von Waldökosystemen. In: Neue inhalte – Umweltwissenschaften. EIPOS Dresden, *17*: 174–177.

PICHLER V., GREGOR J., 1994. Možnosť určenia vlhkostného deficitu ako potenciálneho stresového faktora v bukovom lesnom ekosystéme v Kremnických vrchoch. In: BUBLINEC E. et al. (eds.), Ekologická stabilita, diverzita a produktivita lesného ekosystému. Zvolen, Ústav ekológie lesa SAV: 249–257.

SEDMÁK R., HLADÍK M., 2002. Vplyv rozličného spôsobu výchovy na hodnotovú produkciu predrubného bukového porastu. Acta Facultatis Forestalis Zvolenensis, *44*: 171–186.

SCHIEBER B., KOVÁČOVÁ M., 2002. Phenological observations of beech (*Fagus sylvatica* L.) bud-burst and leaf unfolding. Ekológia (Bratislava), *21*, Suppl. 2/2002: 71–79.

Vplyv hustoty porastu na koncentrácie Zn a Cu v listoch buka

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ABSTRAKT: Práca sa zaoberá reakciou listov bukového porastu na presvetlenie po aplikácii clonného rubu (1989) rozličnej intenzity (zakmenenie 0,3, 0,5, 0,7, 0,9). Výskum prebiehal v r. 1996–1997 na predrastavých, úrovňových a vrastavých vzorníkoch, reprezentujúcich strednú hrúbku porastu pre všetky študované plochy. Získané údaje sa porovnávali oddelene

pre listy odobraté z vrchnej, strednej a spodnej tretiny koruny. V niektorých prípadoch sa potvrdil štatisticky významný vplyv sily ťažbového zásahu ako aj ostatných faktorov na koncentrácie Zn a Cu – na hladine významnosti α = 0,05. Zistili sme významný vplyv na koncentráciu sledovaných prvkov, ich celkové množstvo (závislé od hmotnosti listov na skúmaných plochách) ako aj ich množstvo v listoch jednotkových stromov. Článok nadväzuje na našu prácu, zameranú na výskum koncentrácií Mn a Fe v bukových listoch.

Kľúčová slova: *Fagus sylvatica* L.; lístie; koncentrácia; zinok; meď; clonný rub

Koncentrácie Zn a Cu v asimilačných orgánoch sme sledovali na štyroch plochách s rôznym zakmenením. Po aplikácii clonného rubu v roku 1989 vzniknuté plochy sa navzájom líšili hustotou porastu: plocha H (intenzívny zásah) mala zakmenenie 0,3, plocha M (stredne intenzívny zásah) – 0,5, plocha L (mierne intenzívny zásah) – 0,7. Jedna plocha zostala bez zásahu, s pôvodným zakmenením 0,9 (C – kontrola). Údaje o vývoji dendrometrických veličín po ťažbovom zásahu v roku 1989 v porovnaní s rokom 1996 uvádzame v článku Machava a Barna (2005).

Zinok je všeobecne považovaný za vysoko pohyblivý prvok v rastlinách, avšak niektorí autori sa nezhodujú s týmto tvrdením. Závisí to od jeho množstva a prístupnosti, rozpustné formy Zn sú pre rastliny ľahko prijateľné. Jeho príjem je u rastlín kontrolovaný cez jeho obsah v pôdnom roztoku. Fyziológia a biochémia škodlivých účinkov na rastliny je veľmi podobná ostatným mikroprvkom, avšak Zn nepôsobí až tak toxicky. Jeho optimálne obsahy v lesných drevinách sú v rozsahu 15–80 mg/kg (Bublinec 1994) a odpovedajú podľa Maternu (1963) najnižšej prijateľnej koncentrácii 19 mg/kg pre dreviny. Zn je esenciálny prvok a jeho deficiencia sa prejavuje vo viacerých formách, ako sú chloróza listov, miestna nekróza, podstatne menšia listová plocha, predčasný opad listov, spomalený rast a plodnosť stromov.

Meď je pri porovnaní s ostatnými mikroprvkami málo pohyblivá. Hlavná časť sa akumuluje hlavne v koreňoch a listovom tkanive. Akumulácia Cu v jednotlivých častiach rastlín je variabilná, ale jej celkový obsah je pomerne nižší než u zinku. Stanovené hodnoty sa posudzujú podľa prípustných koncentrácií 2–14 mg/kg (Bublinec 1994). Najvyššie hodnoty boli zistené vo výhonkoch a súvisia s jednotlivými fázami rastu.

Hlavný cieľ práce je posúdiť celkové trendy koncentrácií Cu a Zn v listoch buka v meniacich sa ekologických podmienkach v dôsledku rôznej hustoty porastu po aplikácii clonného rubu. Výskum bol zameraný na celú korunu buka a sledoval sa vplyv sociálneho postavenia stromov na jednotlivých plochách a význam postavenia listov v korune (vrchná, stredná a dolná tretina) na tieto koncentrácie.

Najvyššia koncentrácia Zn 87,05 mg/kg bola stanovená vo vrchnej tretine predrastavých stromov na ploche C a najnižšia hodnota 32,81 mg/kg v strednej tretine úrovňových stromov na ploche M. Koncentrácie Zn vo všetkých tretinách predrastavých, úrovňových a vrastavých stromov na plochách C, L a M majú rovnakú tendenciu – klesajúcu od predrastavých k vrastavým a úrovňovým stromom. Výnimkou bola stredná časť na ploche C, kde najvyššie koncentrácie boli stanovené pri vrastavých stromoch, čo súhlasí aj s trendom Zn na ploche H.

Nižšie hodnoty pri úrovňových stromoch sú pravdepodobne spôsobené tým, že odber vzoriek bol v inom roku (1996) ako u ostatných (1997). Najväčší vplyv z klimatických faktorov ovplyvňujúcich koncentráciu skúmaných prvkov má kvalita a kvantita zrážok. Úhrn zrážok vo vegetačnom období (apríl–september) v roku 1997 tvoril iba 61 % z roku 1996. Vplyv rokov predstavoval významný faktor na koncentráciu Zn ($P < 0,00001$) a Cu ($P = 0,00607$). Aj pri medi (tab. 1) najnižšie hodnoty mali úrovňové stromy ($P < 0,00001$). Z tab. 2 vidieť, že priemerné koncentrácie Zn na jednotlivých plochách sa so silou ťažbového zásahu zväčšujú z 53,69 na ploche C na 59,22 mg/kg na ploche H; tento rozdiel kvôli veľkej variabilite nie je štatisticky významný (tab. 1). Priemerné koncentrácie Cu na plochách neboli závislé od hustoty porastu (tab. 1, 2) a nie je medzi nimi významný štatistický rozdiel (α = 0,05).

Na plochách so silnejším ťažbovým zásahom počet zostávajúcich stromov je menší, stromy majú viac rastového priestoru a produkujú viac biomasy (Barna 2001). To sa týka aj možnosti odberu živín z pôdy. Preto na porovnanie sledovaných parametrov vztiahnutých na rovnako veľkú plochu bol definovaný pojem „jednotkový strom" (Machava, Barna 2005). Keď koncentráciu alebo množstvo Zn a Cu v listí z každého vzorníka (N) vynásobíme konštantou, ktorá sa rovná hodnote zakmenenia danej plochy (v našom prípade 0,3; 0,5; 0,7 a 0,9 – v rovniciach označené *SD* – stand density), dostane-

me veličinu vztiahnutú na jednotkový strom. Medzi skúmanými plochami sme takýmto spôsobom zistili nasledovné vzťahy: $N \times (SD)$ – korešponduje jednotkovému stromu a vyjadruje stav, ktorý sa dosiahne pri úplnom zakmenení. $N \times (1/SD)$ – vyjadruje, o koľko viac živín prijme strom pri rôznom zakmenení. Pre úplné vyrovnanie hodnôt v tab. 4 a 6 by sme museli do rovnice zapojiť ďalšie faktory, vplývajúce na konkrétne skúmané vzorníky, resp. zväčšiť skúmaný súbor. Koncentrácie Zn a Cu v asimilačných orgánoch buka lesného upravené spomenutým vzťahom vykazovali štatisticky významnú lineárnu závislosť k hustote porastu (plochy H, M, L, C) ako aj k sociálnemu postaveniu stromov (predrastavý, úrovňový a vrastavý). Na hladine významnosti α = 0,05 sa štatisticky významne potvrdili vzťahy medzi intenzitou zásahu na plochách H–C (zakmenenie 0,3–0,9) a:

– koncentráciou Zn v listoch vrastavých stromov (rovnica 1),
– koncentráciou Zn a množstvom sušiny listov u vrastavých stromov (2),
– množstvom Zn akumulovaného v listoch predrastavého (3) a vrastavého (4) bukového vzorníka,
– množstvom Zn akumulovaného v listoch jednotkového vrastavého stromu (5).

Pri medi je to závislosť korelačného vzťahu:
– medzi intenzitou zásahu a jej koncentráciou v listoch pri úrovňových a vrastavých stromoch (6, 7),
– medzi koncentráciou Cu a množstvom sušiny listov pri vrastavých stromoch (8),
– medzi intenzitou zásahu a množstvom Cu akumulovanej v listoch vrastavého buka (9) a akumulovanej Cu v listoch jednotkového stromu pri vrastavých a úrovňových jedincoch (10 a 11).

Tieto výsledky boli získané z obmedzeného počtu bukových vzorníkov (12), preto pri úplnom zovšeobecnení záverov by sme súbor skúmaných vzorníkov museli zväčšiť.

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