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The influence of stand density on Mn and Fe concentrations in beech leaves

J. Machava[1], **M. Barna**[2]

[1]*Faculty of Forestry, Technical University Zvolen, Zvolen, Slovak Republic*
[2]*Institute of Forest Ecology of the Slovak Academy of Sciences, Zvolen, Slovak Republic*

ABSTRACT: A shelterwood system is widely used in forest management practice. Favourable ecological conditions for the growth of desired natural seedlings are provided by a successive canopy reduction. The impact of these changed conditions is reflected to the greatest extent in the morphology and structure of beech leaves. Differences in the leaf structure can mainly be seen between sunlit and shaded leaves and are themselves manifested in changes of element contents in leaves according to the respective conditions. The relationships between analysed variables were studied during research (1996–1997) in stands of different initial stand density (0.3, 0.5, 0.7 and 0.9), resulting from the shelterwood cut of different intensity (1989). The second criterion was the social status of a tree in stands (dominant, codominant and subdominant) and the third one was the position of leaves in the tree crown (upper, middle and lower part of crown). In the framework of this research the concentrations of Mn and Fe including other macronutrients in beech leaves were evaluated. This paper deals only with manganese and iron due to a limited range of pages. The concentrations of Mn a Fe were studied in beech leaves collected from upper, middle and lower parts of beeches with a different social status. In some cases, statistically significant influences of shelterwood cutting intensity on the analysed variables (metal concentration, dry weight, etc.) were proved at a significance level $\alpha = 0.05$. It applies to manganese quantity accumulated in leaves of dominant, codominant, and subdominant trees, unit trees, Mn concentration in assimilatory organs, dry mass, iron concentration, etc.

Keywords: *Fagus sylvatica* L.; leaf; concentration; iron; manganese; shelterwood cutting

Shelterwood reduction is used in forest management practice mainly in the shelterwood system. The advantage of forest regeneration through shelterwood cutting is that convenient ecological conditions for the origination and survival of desired natural seedlings are provided by a successive canopy reduction and by the parent stand shelterwood influence (Ray et al. 1999; Pastur et al. 2000). The growth potential of the remaining individuals of parent stand is utilised (Greguš 1976). By shelterwood cutting the stand ecological conditions are changed from full canopy to a clear-cut area situation (Korpeľ et al. 1991).

After logging, light and climatic relations are thus changed appropriately. Due to the good adaptability of beech leaves to a local climate the change of their morphology and structure is mostly conditioned by certain growth conditions during establishment and differentiation of assimilatory organs (Roloff 1987). Differences in the leaf structure manifest themselves mainly between sunlit and shaded leaves (Hunter 1997; Masarovičová et al. 1996). Plants adaptable to shadow usually form large leaf surfaces with a higher content of cellulose and water in the living tissue. On the contrary, plants exposed to high sunshine form smaller leaf surfaces, several mesophyll layers, thicker epidermis and cuticle and additional characteristic properties (Larcher 1988; Lichtenthaler et al. 1981).

Plants contain different quantities of Mn depending on plant species, evolutionary stage and

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plot conditions. Mn as a micronutrient occurs in leaves of forest tree species in large quantities up to 3,000 mg/kg (Machava 2002). Kovalskij (1977) stated the following concentration range for agricultural plants: 0.2–122 – insufficient, 2–3,110 – normal and 49–11,000 mg/kg – excessive. Plants take up mainly manganese (Mn^{2+} or Mn^{3+} – chelate forms) bound to organic substances and to a small extent in a water-soluble form (Finck 1969). Mn activates enzyme systems, participates in photosynthesis and takes part in chlorophyll production. Mn influences Fe redox transformation. At Mn deficiency a large part of Fe is in a reduced form that acts toxically on a plant cell. At Mn oversupply whole Fe bound in a cell is in an oxidising state, physically inactive and initiates chlorosis. However, total amounts of these elements can vary arbitrarily.

Iron uptake by plants is not unambiguously illustrated. Owing to easily oxidisable forms, Fe usually quickly turns into insoluble compounds and the free ionic form almost does not exist in plants. Its transport and function in plants are conditioned by specific transport and acceptor systems.

Fe accumulates mainly in chloroplasts and takes part in a photosynthetic apparatus. Nearly 90% of the whole amount of Fe in leaves is incorporated into chloroplasts. Its transport into chloroplasts is probably controlled by the cytoplasm. This means that Fe gets in chloroplasts after the saturation of the cytoplasm structure. On account of that, chlorosis of assimilatory organs manifests itself at first and then growth disorders and defects in the cytochrome system occur. Chlorosis can be caused by Fe deficiency or induced by an excessive amount of Mn (Mn-chlorosis). According to Mengel (1984) such chlorosis occurs at Mn content < 100 mg/kg. Likewise, the limit for Fe concentrations in assimilatory organs has not been determined in Slovakia until now. Stefan et al. (1997) stated the optimal Fe concentration in assimilatory organs 200 mg/kg, which corresponds with the value quoted by Maňkovská (2001).

In general, Fe and Mn are interrelated in their metabolic functions, and their appropriate proportion (the Fe/Mn ratio should range from 1:1.5 to 2.5) is necessary for healthy plants (Kabata-Pendias, Pendias 1992).

This paper deals with changes in Mn and Fe concentrations in beech leaves owing to altering ecological conditions caused by shelterwood cutting of different intensity. Research was conducted in the whole tree crown, aimed at the social status of trees in the stand and leaf position in the sample tree crown (vertically divided into crown parts – upper, middle and lower – each equals to one third of the crown length).

MATERIALS AND METHODS

Study area

The beech stand was studied in Central Slovakia (48°38´N and 19°04´E) at the Ecological Experimental Station (EES) Kremnické vrchy Mts. The age of the stand was 100 years (at the time of sampling) and it is situated on a western slope with a gradient up to 20°, at an altitude from 450 to 470 m, the mean annual temperature is 8.2°C, in the vegetation period 14.9°C, the mean annual total precipitation is 664 mm and in the vegetation period 370 mm. The main stand-forming association is *Dentario bubliferae-Fagetum* Zlatník 1935, with locally admixed *Carici pilosae-Fagetum* Oberd (1958). From the

Table 1. Main characteristics of beech stands on sampling plots (H – high, M – medium, L – low intensity of cutting and C – control plot)

Plot	Year	Stem density (ha)	Height (m)	dbh[a] (cm)	Volume[b] (m^3/ha)	Stand density
H	1989	160	27.7	32.0	193.7	0.3
	1996	160	29.3	37.5	280.2	0.4
M	1989	243	26.9	31.3	256.8	0.5
	1996	229	28.6	35.4	353.4	0.6
L	1989	397	25.4	29.4	398.9	0.7
	1996	363	28.2	32.7	497.1	0.8
C	1989	700	23.6	25.3	571.2	0.9
	1996	633	26.3	26.6	619.8	0.9

[a]mean diameter at breast height, [b]volume of large wood (> 7 cm d.o.b.)

aspect of Natura 2000 the EES plot belongs to the biotope *Asperulo-Fagetum* beech forests, code: 9130.

The influence of beech stand shelterwood cutting of different intensity on Fe and Mn concentrations in leaves was investigated on four partial plots (PPs) of EES. In February 1989 shelterwood cutting of different intensity was done corresponding to several phases. After regeneration cutting in 1989, the original stand density 0.9 was changed to the following levels: – to **0.3** on the **H** plot (high intensity cutting), – to **0.5** on the **M** plot (medium intensity cutting), – to **0.7** on the **L** plot (low intensity cutting). The **C** (control) plot remained intact with the original stand density **0.9**. The aim of this intervention was first of all to remove diseased, dying trees and trees of very low quality as well as individuals of admixed species. Mensurational variables on PPs from 1989 (cutting) compared to those from 1996 (sampling) are shown in Table 1. Other characteristics of the locality and research on the plots were described in previous papers (Bublinec, Dubová 1993; Pichler, Gregor 1994; Kellerová et al. 1997; Gregor 1999; Zach et al. 2002; Schieber et al. 2003).

The evaluation of the influence of shelterwood cutting intensity on plot parameters is based on the assumption that all plots have similar properties, including Mn and Fe contents of soil.

To examine the chemical composition of beech leaves, codominant, dominant and subdominant sample trees were selected according to Kraft's tree classification on each of all four PPs (C, L, M, and H). Twelve trees were gradually cut, leaf samples were processed and analysed.

Sample tree harvesting began after the physiological maturity of leaves was achieved (23 July–10 September 1996, 1997).

Plant material

Leaf position in the tree crown was the first criterion for leaf sampling. So leaves were sampled from the upper, middle and lower third of tree crowns. The social status of trees in the stand was the second criterion for the complex evaluation of changes in concentrations of chosen elements as a reaction to altered climatic conditions in the investigated stands. The selected group of mean trees was divided into three sub-groups. That means the sample trees were from 4 stands with different intensity of cutting (intensive, medium, low and control; the third criterion) and in each stand there were dominant, subdominant and codominant trees.

After drying, leaf samples were homogenised by the Fritsch planetary micromill pulveriser 7. During a digestion process a 0.5g sample, dried at 85°C to a constant weight, was mixed with 5 ml of concentrated HNO_3, p.a. and treated in a microwave oven at the output $P = 60\%$ during 12 minutes (Key Reference, CEM 1988). Filtration was carried out through filter paper Filtrak 391 and sample solution was made up to a volume of 50 ml. Element concentrations in the sample solution were determined by atomic absorption spectroscopy (AAS) on GBC Avanta 900 spectrometer. Besides Mn and Fe, other elements including Cu, Zn (yet unpublished) and macronutrients Ca, Mg, K and Na (Barna, Bublinec 2002) were determined. Mutual relationships between individual elements were assessed, including the Mn:Fe ratio.

RESULTS AND DISCUSSION

Mn and Fe concentrations according to cutting intensity

Mn concentrations determined in leaves from all plots ranged from 371.50 to 953.23 mg/kg. The lowest concentration was recorded in leaves from the middle part of the crown of codominant tree on plot L. The highest one was determined in leaves from the upper part of codominant beech tree on plot H.

On **plot C** the Mn highest concentrations were recorded in dominant beech trees (lower part – 939.61, middle part – 863.01 and upper part – 794.92 mg/kg). Then subdominant trees followed and the lowest ones were in codominant trees. Comparing the concentrations in the order dominant, subdominant and codominant trees, the highest concentrations were recorded in lower parts (939.61; 596.97 and 762.41 mg/kg), followed by the middle and the upper part of trees, with the exception of the codominant tree.

On **plot L** the highest concentrations were, similarly like on plot C, in dominant trees (mean 776.59 mg/kg), lower ones were in subdominant trees and the lowest in codominant trees. In subdominant trees the highest Mn concentration was recorded in the lower part of the crown. In codominant trees the concentrations were balanced and in dominant trees the concentration was highest in the upper part.

On **plot M** the highest Mn concentrations were in codominant trees in the upper third of the crown and in subdominant and dominant trees in the middle part. On plot **H** with the highest intensity of cutting these highest values in subdominant and dominant trees were shifted to the lower part of crowns. In codominant trees the highest value was still in the upper part, which was the maximum value of all determined concentrations at the same time.

The Fe concentrations on plot **C** increased in leaves from codominant to dominant and subdominant trees in all three parts. The highest values were in the middle part of crowns in subdominant (188.04 mg/kg) and codominant trees (97.32 mg/kg) and in the lower part in dominant trees (158.76 mg/kg).

On **plot L** Fe concentrations in leaves increased in the upper and middle parts from codominant to dominant and subdominant trees, only in the lower part it was from dominant to codominant and subdominant trees. The highest content of 208.61 mg/kg was recorded in the lower part of subdominant trees and the lowest content of 91.43 mg/kg in the upper part of codominant trees, which accounted for approximately one half of the value determined in the same place in subdominant trees. The concentrations from the upper to the lower part of trees increase with the exception of dominant trees in which the highest concentration was found out in the middle part.

On **plot M** Fe concentrations in leaves increased from codominant to dominant and subdominant trees with the exception of the upper part, where the highest value of 168.51 mg/kg was in dominant trees. In dominant trees Fe contents in the whole crown were approximately equal, but the lowest one was in the lower part. The highest Fe content of 178.99 mg/kg was measured in subdominant trees in the lower part while the lowest value of 80.31 mg/kg was in codominant trees in the middle part.

On **plot H** Fe concentrations also increased from codominant to subdominant and dominant trees, but this increasing trend from the upper to the lower part was found out only in subdominant trees. In dominant trees the highest value was in the middle and the second highest in the lower part of the crown. In codominant trees this trend was opposite when the highest concentration was in the upper part. The highest content of 319.42 mg/kg was in dominant trees in the middle part while the lowest value of 126.95 mg/kg was determined in codominant trees in the lower part.

Mn and Fe concentrations according to social status

The influence of regeneration cutting on Mn and Fe concentrations in leaves with respect to the social status of beech parent stands is discussed in the following part.

Mean Mn concentrations in leaves from the examined beech trees and in leaf dry mass are presented according to social status (dominant, codominant and subdominant) and shelterwood cutting intensity (high – initial stand density 0.3, medium – 0.5, low – 0.7 and control – 0.9) in Table 2. The most remarkable relationships between determined Mn concentrations in leaves and in dry mass of assimilatory organs (DMAO) were recorded in **dominant** trees. Mn concentrations decreased in beech leaves with the simultaneous decrease of stand density from plot L (0.7) to plot M (0.5), but in the most intensive cutting (plot H – 0.3) Mn concentration suddenly increased to 705.02 mg/kg. Conversely, DMAO from one beech increased from plot L to M (21.43 kg dried leaves) and on plot H this variable dropped to 16.34 kg. The courses of DMAO and Mn concentration in assimilatory organs were opposite and no linear dependence was found out. However, Mn content in the foliage of one beech (Table 3) increased with the increasing intensity of shelterwood cutting (from plot L to H) with the exception of the control plot, where the highest value of 12,364.30 mg was recorded. Without taking into account this value, linear regression was established between the amount of Mn accumulated in foliage from one tree and the cutting intensity (from plot L to H) on the respective plots (equation 1). For example: at SD = 0.4 the Mn amount accumulated in beech leaves was 11,117.24 mg. This increase of Mn amount in beech leaves with increasing cutting intensity can be explained by the fact that the drop of Mn concentration (865.85 to 499.79 mg/kg) is balanced by an increase in DMAO and vice versa. In other words, the increase of Mn accumulation in beech foliage with increasing cutting intensity can be caused mainly by the enlarged root system (Barna, Kodrík 2002), consequently the higher uptake of nutrients by trees and by the higher quantity of absorbed solar energy through leaves.

The validity of this relationship, but only without the values from plot C, can be explained by an assumption that the regime of nutrient supply on other plots was disturbed by silvicultural practices and due to the Mn uptake it was the highest on plot C. Further, Mn concentrations in leaves and DMAO are variables with a reciprocal trend. Actually, Mn quantity in leaves of one beech tree multiplied by the respective stand density (from 0.9 to 0.3) gives the variable related to so called "unit tree" and corresponds to an equally large area. Concentration or amount of Mn and Fe in sample tree leaves (N) multiplied by the constant equalling to stand density of a given stand (0.3; 0.5; 0.7 and 0.9 – in equations marked by SD – stand density) gives the variable related to the unit tree. The following relationships

Table 2. Mn concentration in foliage of beech on plots with different stand density (H, M, L, C see Table 1) and total dried leaves mass from samples

Plot – initial	Dominant tree		Codominant tree		Subdominant tree	
stand density	Mn (mg/kg)	leaves (kg)	Mn (mg/kg)	leaves (kg)	Mn (mg/kg)	leaves (kg)
H – 0.3	705.02	16.34	847.16	9.55	719.49	7.21
M – 0.5	499.79	21.43	552.93	10.50	531.21	3.13
L – 0.7	776.59	12.78	383.61	8.44	564.01	2.23
C – 0.9	865.85	14.28	542.76	4.79	743.89	1.44
Mean	711.18 ± 155.91	16.21 ± 3.78	581.62 ± 193.26	8.32 ± 2.50	639.65 ± 107.58	3.50 ± 2.57

were confirmed between the plots of EES: N × (SD) corresponds to 1 unit tree and is supposed to be under full density. N × (1/SD) expresses how much more Mn a tree can uptake at different cutting intensity. For the complete smoothing of values shown in Tables 3 and 5, other factors exerting the influence on analysed trees should be substituted into equations and/or the analysed tree groups should be enlarged.

This assumption is confirmed by further linear regression (equation 2) between *Mn amount in foliage from a unit tree* and decreasing stand density (but in this case from plot C to H).

$y = 1{,}271.42 - 3{,}987.95 \times \text{SD}, r = -0.99996$ (1)
(Mn in foliage of 1 beech/SD dominant)
$y = -660.75 + 12{,}303.95 \times \text{SD}, r = 0.9727$ (2)
(Mn in unit beech foliage/SD dominant)
where: SD – stand density.

The increasing trend of Mn concentration in leaves of **codominant** trees was also confirmed (Table 2). Mn content in leaves increased with a decrease of stand density (from plot L to H), when the highest concentration of 847.16 mg/kg was recorded. Mn content in the leaves on the control plot exceeded this range. Again without taking into account this value, linear regression was proved between the Mn concentration in leaves and the cutting intensity on the respective plot (equation 3). The amount of leaf dry mass on individual plots showed a similar trend like in dominant trees, but calculated quantities were more than 1.5 times lower compared to dominant trees. It means that the highest amount of Mn was recorded on plot M (0.5) again. But the lowest value was determined in the control stand and in this case linear regression was again proved between dry mass of leaves and stand density (from plot C to H) (equation 4). The Mn content in foliage of one beech (Table 3) also increased with the higher cutting intensity. Moreover, linear regression was confirmed again between Mn amount accumulated in foliage of one beech and the decreasing cutting intensity (from plot C to H) on the respective plot (5).

$y = 1{,}174.00 - 1{,}158.88 \times \text{SD}, r = -0.9881$ (3)
(Mn concentration in leaves/SD codominant)
$y = 13.22 - 8.17 \times \text{SD}, r = -0.8440$ (4)
(Mass of leaves/SD codominant)
$y = 10{,}645.34 - 9{,}519.89 \times \text{SD}, r = -0.9755$ (5)
(Mn in foliage of 1 beech/SD codominant)
$y = 8.97 - 9.11 \times \text{SD}, r = -0.9161$ (6)
(Mass of leaves/SD subdominant)
$y = 6{,}120.96 - 6{,}376.96 \times \text{SD}, r = -0.8469$ (7)
(Mn in foliage of 1 beech/SD subdominant)

For codominant trees the Mn amount accumulated in the foliage of a unit tree ranged from 2,266 to 2,903 mg per unit tree (Table 3). It means that the Mn uptake by a unit tree was not probably dependent on cutting intensity.

In **subdominant** trees the linear regression between determined Mn concentrations in beech

Table 3. Mn content (10^{-3} g) in foliage from one beech and unit beech on stand with different stand density (H, M, L, C see Table 1)

Plot – initial	Dominant		Codominant		Subdominant	
stand density	tree	unit tree[1]	tree	unit tree	tree	unit tree
H – 0.3	11,520.00	3,456.00	8,090.38	2,427.00	5,187.52	1,556.26
M – 0.5	10,710.50	5,355.20	5,805.77	2,903.00	1,662.69	831.34
L – 0.7	9,924.82	6,947.40	3,237.67	2,266.00	1,257.74	880.42
C – 0.9	12,364.30	11,127.90	2,599.82	2,339.80	1,071.20	964.10

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

Table 4. Fe concentration in foliage of beech on plots with different stand density (H, M, L, C see Table 1) and total dried leaves mass from samples

Plot – initial	Dominant tree		Codominant tree		Subdominant tree	
stand density	Fe (mg/kg)	leaves (kg)	Fe (mg/kg)	leaves (kg)	Fe (mg/kg)	leaves (kg)
H – 0.3	274.54	16.34	144.77	9.55	186.46	7.21
M – 0.5	163.41	21.43	105.19	10.5	170.19	3.13
L – 0.7	159.67	14.28	119.68	8.44	198.40	2.23
C – 0.9	153.37	12.78	94.28	4.79	179.19	1.44
Mean	187.75 ± 58.01	16.21 ± 3.78	115.98 ± 21.83	8.32 ± 2.50	183.56 ± 11.92	3.50 ± 2.57

leaves and stand density was not confirmed, but it existed between DMAO and stand density on the respective plot (6). The highest Mn concentration was determined in beech leaves on plot C (743.89 mg/kg). DMAO increased from stand C to stand H with the most intensive cutting intervention (7.21 kg). The course of Mn amount in leaves from one beech was up-ward from stand C to H, and linear regression (7) between them was proved. Mn amount in leaves from unit tree ranged from 880.42 to 1,556.26 mg, and there was not any statistical dependence.

The influence of cutting intensity on Fe concentrations in leaves represented in Tables 4 and 5 is not so unambiguous as in Mn. Although linear regression between Fe concentrations in leaves and shelterwood cutting intensity (from stand C to H) was confirmed (8), it was only in **dominant** trees and nearly at the confidence limit. Fe concentrations varied in a very small range, in dominant trees it was approximately around 160 mg/kg, only on plot H (0.3) the concentration increased to 274.54 mg/kg. In codominant trees it was around 100 mg/kg, with the exception of 144.77 mg/kg on the same plot and in subdominant trees all concentrations were in the range 170.19–198.4 mg/kg. Relationships between DMAO from individual stands in dominant, codominant and subdominant trees and shelterwood cutting intensity (from stand L to M and H) were evaluated at manganese levels.

$y = 297.93 - 183.63 \times \mathrm{SD},\ r = -0.8173$ (8)
(Fe concentration in leaves/SD dominant)
$y = 5{,}696.86 - 4{,}399.76 \times \mathrm{SD},\ r = -0.9781$ (9)
(Fe in foliage of 1 beech/SD dominant)
$y = 1{,}853.36 - 1{,}443.62 \times \mathrm{SD},\ r = -0.9545$ (10)
(Fe in foliage of 1 beech/SD codominant)
$y = 192.65 + 730.76 \times \mathrm{SD},\ r = 0.9994$ (11)
(Fe in unit beech foliage/SD codominant)
$y = 1{,}649.17 - 1{,}674.65 \times \mathrm{SD},\ r = -0.9000$ (12)
(Fe in foliage of 1 beech/SD subdominant)
$y = 443.87 - 234.95 \times \mathrm{SD},\ r = -0.8190$ (13)
(Fe in unit beech foliage/SD subdominant)

The Fe content (Table 5) calculated per foliage of one beech in dominant trees increased with increasing cutting intensity (stand C to H; 4,485.98 g). Moreover, linear regression between the Fe contents in foliage of one beech and shelterwood cutting intensity was proved (9). Fe amount in *unit tree foliage* on particular plots with respect to cutting intensity slightly decreased. It is caused by the fact that Fe concentrations differed very little (153.37 to 274.54 mg/kg) (Table 4). As for the other Fe concentrations in leaves, this dependence was not confirmed. Further, linear regression was also proved in **codominant** trees between Fe contents in foliage from one beech (10) and the shelterwood cutting intensity (from stand C to H) and the same dependence was demonstrated for Fe amount in unit tree foliage (11) and shelterwood cutting intensity (from stand

Table 5. Fe content (10^{-3} g) in foliage from one beech and unit beech on stand with different cutting intensity (H, M, L, C see Table 1)

Plot – initial	Dominant		Codominant		Subdominant	
stand density	tree	unit tree[1]	tree	unit tree	tree	unit tree
H – 0.3	4,485.98	1,345.80	1,382.55	414.77	1,344.38	403.31
M – 0.5	3,501.88	1,750.90	1,104.50	552.25	532.70	266.35
L – 0.7	2,280.09	1,596.10	1,010.10	707.07	442.43	309.70
C – 0.9	1,960.07	1,764.10	451.60	406.40	258.03	232.23

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

Table 6. Statistical characteristics of Mn and Fe concentration of beech foliage (H, M, L, C see Table 1)

Characteristics	Mn				Fe			
	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 (mg/kg)	757.22	527.98	574.74	717.5	201.92	146.26	159.25	142.69
Error of mean value (mg/kg)	38.73	26.71	58.34	49.94	21.59	25,477.00	13.17	14.41
Standard deviation (mg/kg)	116.19	80.14	175.02	149.83	64.77	32.07	39.51	40.76
Coefficient of variation (s_d%)	15.36	15.18	30.45	20.88	32.08	21.93	24.81	28.77
Curtoses	1.76	–0.19	–0.41	–0.73	0.04	–1.05	–0.30	–2.03
Skewness	–0.40	0.57	0.25	–0.26	0.88	–0.88	–0.59	–0.39
Difference min–max (mg/kg)	425.23	256.44	456.62	463.49	192.47	86.33	117.18	97.88
Minimum (mg/kg)	528.00	417.14	371.50	476.12	126.95	92.66	91.43	90.16
Maximum (mg/kg)	953.23	673.58	828.12	939.61	319.42	178.99	208.61	188.04
Confidence level (95%)	89.31	61.60	134.53	115.17	49.79	24.65	30.37	34.08

L to H). On the control plot, the Mn concentration 406.4 mg/kg exceeded this range.

In **subdominant** trees linear regression was confirmed between Fe amounts (12) in foliage of one beech and stand density (from plot C to H) and the same dependence for Fe contents (13) in the foliage of unit tree.

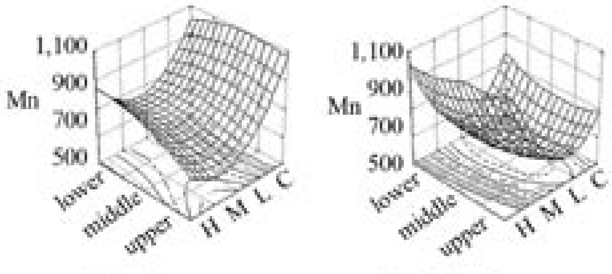
The determined values were statistically evaluated (Table 6). Concentrations of analysed elements can be expressed by some statistical characteristics, but only arithmetic mean, standard deviation and coefficient of variation are the most important for a practical use. The highest concentration of Mn (953.23 mg/kg) was on plot H with the highest cutting intensity and the lowest concentration (371.50 mg/kg) on plot L with the lowest one. The standard deviation (s_x) describes the dispersion of the measured values around the mean value ($\overline{x}$) so that it gives the region $\overline{x} + s_x$, in which a certain number of all numbers x_j occurs. All values occur practically within three standard deviations of the mean ($\mu \pm 3 s_x$) (Šmelko 2000). The higher the values s_x, the greater the dispersion of the measured values and vice versa. Standard deviation values have an unambiguous sequence with stand density. The coefficient of variation (s_d%) is a relative measure of the variability of values. It expresses the standard deviation in the percentage of the arithmetic mean and makes it possible to compare mutually analysed variables in a better way. Table 5 shows that the coefficient of variation had an increasing tendency simultaneously with the decreasing intensity of cutting intervention.

In general, the course of Fe concentrations was opposite compared to Mn concentrations, but mean concentrations shown in Table 6 eliminate this sufficient characteristic. The highest Fe mean concentration was also found out on plot H with the highest cutting intervention, but the lowest one was on the control plot, where the second highest Mn mean concentration was recorded.

Curtosis indicates relative skewness or flatness of the distribution in comparison with normal distribution. Skewness denotes the degree of variable arithmetic distribution around the mean value. These coefficients test the significance of differences between analysed and normal distribution. Because all values are in an interval of (–2, +2), this distribution does not differ from the normal one.

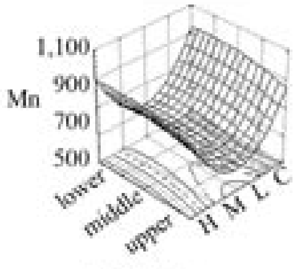
Finally, Fig. 1 shows three-dimensional representation of the measured Mn concentrations. The course of these concentrations is fitted by an appropriate function (Fig. 1), therefore the real course need not be so smooth. Mn concentrations in crowns of dominant beech trees increased proportionally with stand density in each third of the crown (Fig. 1a). The determined concentrations from plot M deviated from this trend (Table 1). This can be partly explained by the fact that mean values are calculated for the whole crown and the sensitivity of these measurements depends on sampling places in crowns. In codominant trees this trend was opposite. The highest concentrations were determined in sample tree leaves from plot H with the cutting of highest intensity (Fig. 1b), which can be explained by the higher Mn uptake by trees. This sequence is a little bit broken by the results from plot L, which are lower than those from the control plot (Table 1).

This trend of concentrations slightly changed in codominant and subdominant trees, the distribution of concentrations in crowns was slightly shifted (Figs. 1b, c). It seems to be the exception from the observed regularity. It follows from all above-mentioned results that the increase of Mn concentration



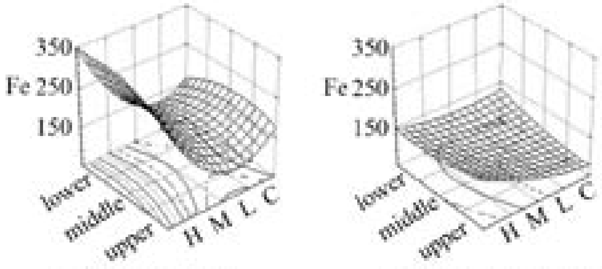
a) Dominant trees

b) Codominant trees



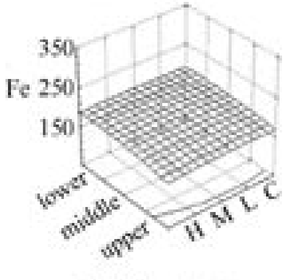
c) Subdominant trees

Fig. 1. Course of Mn concentrations in beech leaves at dominant (a), codominant (b) and subdominant trees (c) according to various cutting intensity (H, M, L, C see Table 1) and part of crown (upper, middle, and lower third)



a) Dominant trees

b) Codominant trees



c) Subdominant trees

Fig. 2. Course of Fe concentrations in beech leaves at dominant (a), codominant (b) and subdominant trees (c) according to various cutting intensity (H, M, L, C see Table 1) and part of crown (upper, middle, and lower third)

in beech foliage and of foliage mass (Barna 2001) with increasing cutting intensity can be explained by the enlarged root system (Barna, Kodrík 2002) and consequently by the higher uptake of nutrients by trees and finally by the higher quantity of absorbed solar energy through leaves.

The mentioned typical differences between trends of Mn and Fe in dominant trees can be seen in Fig. 2. In dominant trees the Fe concentrations did not differ from each other very much in the particular thirds (Fig. 2a), but unlike Mn the highest Fe concentrations were recorded on plot H with the cutting of highest intensity, which is in accordance with conclusions of Barna and Bublinec (2002) that the Ca concentrations in beech leaves increase with increasing cutting intensity. In codominant trees, the difference between the analysed Fe concentrations diminished (Fig. 2b) and in subdominant trees (Fig. 2c) these concentrations varied in a narrow range. It means that the increased intensity of cutting influenced the Fe concentrations in leaves only in dominants trees. In codominant trees it was so to a small extent only. Fe concentrations are more dependent on stand density in comparison with Mn. Similarly like in dominant trees, in codominant trees Fe concentrations in leaves increased with the intensity of cutting in all thirds of the crown (upper, middle and lower thirds – Figs. 2a, b). In subdominant trees this dependence was not proved. Maximum values were determined on plot L while minimum ones on plot M. This proved again that these trees grew under different conditions than the upper storey (Barna 2004).

In other words, the influence of cutting intensity on Fe concentrations in leaves was closely connected with the opening up of the stand and the amount of incident light on foliage.

CONCLUSION

After shelterwood cutting of different intensity was used, the influence of changed stand density on biomass production of beech leaves was statistically proved in codominant and subdominant trees (equations 4 and 6). This statistical dependence was confirmed in other variables. At first, it is concentrations of Mn in leaves of codominant trees (equation 3) and of Fe in leaves of dominant trees (equation 8). Secondly, it is an amount of Mn accumulated in foliage of one beech in dominant, codominant and subdominant trees (equations 1, 5 and 7) and an amount of Fe in foliage of one beech in dominant, codominant and subdominant trees (equations 9, 10 and 12). And thirdly, it is an amount of Mn accumulated in the foliage of a unit tree in dominant trees (equation 2) and an amount of Fe in the foliage of a unit tree in codominant and subdominant trees (equations 11 and 13).

Although the statistically significant relationship between Mn concentrations in leaves and cutting intensity in codominant trees was proved by omitting the Mn concentration on plot C, the statistically significant relationships were confirmed for an Mn amount accumulated in beech foliage at all tree social statuses and for Mn accumulated in the foliage of a unit tree in dominant trees. In codominant trees the latter dependence was not proved, but in this case the beech takes up Mn through the root system independently of cutting intervention intensity.

A similar situation was in the Fe amount accumulated in leaves while a statistically significant dependence was proved for Fe accumulated in the foliage at all tree social statuses and in a unit tree in codominant and subdominant trees.

Linear regression between the studied variables of *Fagus sylvatica* showed the way in which the micronutrients Mn and Fe were taken up by the root system and accumulated in leaves by a beech tree.

The increase or decrease of Mn concentrations in leaves of dominant trees was opposite in comparison with the trend of leaf biomass. The highest quantity of Mn accumulated in leaves of one beech on plot C can be explained by the fact that silvicultural practices disturbed the uptake regime of nutrients on other plots. Linear regression was proved only by omitting this value. But in Mn quantities recalculated per unit tree, linear regression was proved for all variables from all 4 analysed plots.

The above-mentioned research results show that the changes of Mn concentrations in dominant trees and of Fe concentrations in codominant trees were closely related with the total weight leaves in a beech crown. This was expressed by the correlation coefficient in equations (1) compared to (2) and the same for equations (10) and (11), which have the opposite sign. The quantity of Mn accumulated in foliage from one unit beech tree decreased linearly from plot C to H (2) and in the quantity of Fe this statistically significant relationship was valid from plot L to H (11). This decreasing trend was caused by the fact that the quantities of Mn and Fe accumulated in leaves of a unit tree decreased with increasing cutting intensity. This dependence was not observed in other trees.

The ratio of Mn to Fe contents should be in the range 1.5–2.5 (Kabata-Pendias, Pendias 1992), however in our case the value 2.5 was recorded only on plot H in dominant trees. This ratio increased for other alternatives. The highest was recorded in codominant trees on plot M.

References

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., 2004. Adaptation of European beech (*Fagus sylvatica* L.) to different ecological conditions: leaf size variation. Polish Journal of Ecology, *52*: 35–45.

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

BARNA M., KODRÍK M., 2002. Beech biomass distribution after shelterwood cutting according to tree social status. Ekológia (Bratislava), *21*: 61–73.

BUBLINEC E., DUBOVÁ M., 1993. Seasonal dynamics of input of sulphates in the Central European beech and spruce ecosystems. Ekológia (Bratislava), *12*: 449–458.

FINCK A., 1969. Pflanzen-Ernährung in Stichworten. Kiel, Verlag Ferdinad Hirt: 200.

GREGOR J., 1999. Vplyv denzity bukového porastu a reliéfu na vlhkosť pôdy. Zvolen, TU, Vedecké štúdie 7/A: 56.

GREGUŠ C., 1976. Hospodárska úprava maloplošného rúbaňového lesa. Bratislava, Príroda: 304.

HUNTER J.C., 1997. Correspondence of environmental tolerances with leaf and branch attributes for six co-occurring species of broadleaf evergreen trees in northern California. Trees, *11*: 169–175.

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

KELLEROVÁ D., BUBLINEC E., JANÍK R., 1997. Expeditive method for the measurements of proton load and its utilization in beech ecosystems. Ekológia (Bratislava), *16*: 17–22.

KORPEĽ Š. et al., 1991. Pestovanie lesa. Bratislava, Príroda: 472.

KOVALSKIJ V.M., 1977. Geochemische Ökologie, Biogeochemie. Berlin, VEB Deutscher Landwirtschaftsverlag: 353.

LARCHER W., 1988. Fyziologická ekologie rostlin. Praha, Academia: 368.

LICHTENTHALER H.K., BUSCHMANN C., DÖL M., FIETZ H.J., BACH T., KOZEL U., MEIER D., RAHMSDORF U., 1981. Photosynthetic activity, chloroplast, ultrastructure, and leaf characteristics of high-light and low-light plants and of sun and shade leaves. Photosynthesis Research, *2*: 115–141.

MACHAVA J., 2002. Forms of Manganese Bounds and its Concentration in Soil and Plants. Folia oecologica, *29*: 183–198.

MAŇKOVSKÁ B., 2001. Concentration of nutrient elements and microelements in the needles of *Abies alba* Mill. as an environmental indicator in the Carpathian Mts. Journal of Forest Science, *47*: 229–240.

MASAROVIČOVÁ E., CICÁK A., ŠTEFANČÍK I., 1996. Ecophysiological, biochemical, anatomical and productional characteristics of *Fagus sylvatica* (L.) leaves from regions with different degree of immission impact. Ekológia (Bratislava), *15*: 337–351.

MENGEL K., 1984. Ernährung und Stoffwechsel der Pflanze. Jena, VEB Gustav Velag: 436.

PASTUR G.M., CELLINI J.M., PERI P.L., VUKASOVIC R.F., FERNANDEZ M.C., 2000. Timber production of *Nothofagus pumilio* forests by a shelterwood system in Tierra del Fuego (Argentina). Forest Ecology and Management, *134*: 153–162.

PICHLER V., GREGOR J., 1994. The possibility of moisture deficit determination as a potencial stressfactor in the beech forest stand on the EES Kremnické vrchy Mountains. In: BUBLINEC E. et al. (eds.), Ecological stability, diversity and productivity of forest ecosystems. Zvolen, Institute of Forest Ecology: 249–257.

RAY D.G., NYLAND R.D., YANAI R.D., 1999. Patterns of early cohort development following shelterwood cutting in three Adirondack northern hardwood stands. Forest Ecology and Management, *119*: 1–11.

ROLOFF A., 1987. Morphologie der Kronentwicklung von *Fagus sylvatica* L. (Rotbuche) unter besonderer Berücksichtigung neuartiger Veränderungen. I. Morphogenetischer Zyklus, Anatomalien infolge Prolepsis und Blattfall. Flora, *179*: 355–378.

SCHIEBER B., KOVÁČOVÁ M., KUKLA J., 2003. Fenológia a energetický obsah nadzemnej biomasy druhu *Fragaria vesca* (L.) v bukovom ekosystéme. In: TARABA B. (ed.), Kalorimetrický seminář 2003, Suchá Rudná. Ostrava, Ostravská univerzita: 53–56.

STEFAN K., FÜRST A., HACKER R., BARTELS U., 1997. Forest foliar condition in Europe. EC-UN/ECE-FBVA, Brussels: 207.

ŠMELKO Š., 2000. Dendrometria. Zvolen, TU: 399.

ZACH P., HARZ B., KULFAN J., TOPP W., ZELINKOVÁ D., ANDERSON J., 2002. Dispersal of *Taphrorychus bicolor* (*Coleoptera, Scolytidae*): males as more active dispersers and unsuccessful colonizations of the beetle on beech trees. Ekológia (Bratislava), *21*, Supplement 2/2002: 152–158.

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Vplyv hustoty porastu na koncentrácie Mn a Fe v listoch buka

J. Machava[1], M. Barna[2]

[1]*Lesnícka fakulta, Technická univerzita vo Zvolene, Zvolen, Slovenská republika*
[2]*Ústav ekológie lesa SAV, Zvolen, Slovenská republika*

ABSTRAKT: Výhodou clonného rubu vo vzťahu k materskému porastu je, že stromy po uvoľnení nasadia zvýšený, tzv. svetlostný prírastok. Tento prírastok umožňuje využiť rastovú potenciu kvalitných jedincov na produkciu hrubších sortimentov. Zmena rastových podmienok, vplývajúca na morfológiu a štruktúru listov, sa prejavila aj v obsahu mikroživín (Mn a Fe). Výskum (1996) bol robený na plochách s rozdielnym počiatočným (1989) zakmenením (0,3, 0,5, 0,7, 0,9). Druhým kritériom bolo sociálne postavenie stromu v poraste (nadúrovňový, úrovňový a podúrovňový) a tretím miesto rastu listov v korune (horná, stredná a dolná tretina koruny). Lineárnou regresiou v niektorých prípadoch sme potvrdili štatisticky významný vplyv intenzity clonného rubu a ďalších sledovaných veličín na koncentrácie mikroživín pri hladine významnosti $\alpha = 0,05$. Je to medzi: množstvom Mn akumulovaného v asimilačných orgánoch pri nadúrovňových, úrovňových a podúrovňových stromoch (rovnice 1, 5 a 7); množstvom Mn akumulovaného v asimilačných orgánoch jednotkových nadúrovňových stromov (rovnica 2); koncentráciou Mn v lístí úrovňových stromov (rovnica 3); hmotnosťou sušiny asimilačných orgánov úrovňových a podúrovňových stromov (rovnice 4 a 6); koncentráciou Fe v asimilačných orgánoch nadúrovňových stromov (rovnica 8); množstvom Fe akumulovaného v lístí nadúrovňových, úrovňových a podúrovňových stromov (rovnice 9, 10 a 12); množstvom Fe akumulovaného v lístí jednotkových úrovňových a podúrovňových stromov (rovnice 11 a 13).

Kľúčové slova: *Fagus sylvatica* L.; lístie; koncentrácia; železo; mangán; clonný rub

Účinok clonného rubu na koncentrácie Mn a Fe v asimilačných orgánoch, ktoré môžu poslúžiť ako indikátor zdravotného stavu a ekologickej stability buka lesného, bol sledovaný na bukovom Experimentálnom ekologickom stacionári (EES) pri Kováčovej v Kremnických vrchoch (stredné Slovensko, 48°38´ a 19°04´). Po aplikácii clonného rubu v roku 1989 bol EES rozdelený na 4 plochy, ktoré sa navzájom líšili zakmenením: 0,3 – plocha H (intenzívny zásah), 0,5 – plocha M (stredne intenzívny zásah), 0,7 – plocha L (mierne intenzívny zásah). 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 sú v tab. 1.

Rastliny obsahujú Mn v rôznych množstvách (až do 3 000 mg/kg) (Machava 2002), závisiac od druhu, stupňa vývoja a lokálnych podmienok. Mn aktivuje enzýmové systémy, zúčastňuje sa na fotosyntéze a podieľa sa na tvorbe chlorofylu. Mn ovplyvňuje redoxnú premenu Fe. Pri nedostatku Mn väčšia časť Fe je v redukovanej forme, ktorá pôsobí na rastliny toxicky. Pri nadmernom obsahu Mn je Fe viazané v bunke v oxidačnom stave, je fyziologicky inaktívny a iniciuje chlorózu. Optimálny pomer aktívneho Mn : Fe by mal byť v rozmedzí 1 : 1,5–2,5. Avšak celkové obsahy týchto prvkov môžu byť ľubovolné.

Príjem Fe rastlinami nie je jednoznačne objasnený, existujú len domnienky o jeho vstupe do rastlín. Jeho transport a funkcie v rastlinách sú podmienené špecifickými transportnými a akceptorovými systémami. Fe sa hlavne ukladá v chloroplastoch a zúčastňuje sa tak na tvorbe fotosyntetického aparátu. Jeho prechod do chloroplastov je pravdepodobne kontrolovaný cytoplazmou. Z tohoto dôvodu sa najskôr prejaví chloróza asimilačných orgánov a až potom dochádza k poruchám rastu a v cytochrómovom systéme. Chloróza nemusí byť spôsobená iba nedostatkom Fe, ale môže byť indukovaná nadmerným množstvom Mn alebo Ca. Pri Mn je to inhibícia príjmu Fe a pri Ca je to zvýšenie pH, ktoré je spojené s imobilizáciou Fe.

Na skúmaných plochách po aplikácii clonného rubu rôznej sily vznikla rôzna hustota porastu. Na porastoch so silnejším ťažbovým zásahom počet zostavajúcich 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". Keď koncentráciu alebo množstvo Mn a Fe v lístí 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), dostaneme veličinu vztiahnutú na jednotkový strom. Medzi čiastkovými plochami EES sme takýmto spôsobom zistili nasledovný vzťah: N × (SD) korešponduje jednotkovému stromu a vyjadruje stav, ktorý sa dosiahne pri úplnom zakmenení. N × (1/SD) vyjadruje, o koľko viac Mn prijme strom pri rôznom zakmenení. Pre úplne vyrovnanie hodnôt v tab. 3 a 5 by sme museli do rovnice zapojiť ďalšie faktory, vplývajúce na konkrétne skúmané vzorníky, resp. zväčšiť skúmaný súbor.

Vplyv ťažbového zásahu na koncentrácie Mn a Fe u buka lesného, sledovaný v roku 1996–1997, sa ukázal štatisticky významný jednak podľa hustoty porastu (plochy H, M, L, C), jednak aj podľa sociálneho postavenia stromov (nadúrovňový, úrovňový a podúrovňový). Na hladine významnosti $\alpha = 0,05$ sa štatisticky významne potvrdili vzťahy medzi intenzitou zásahu:

a) na plochách H–L, resp. C (zakmenenie 0,3–0,7, resp. 0,9) a množstvom Mn akumulovaného v asimilačných orgánoch pri nadúrovňových, úrovňových a podúrovňových stromoch (rovnice 1, 5 a 7),
b) na plochách H–C (zakmenenie 0,3–0,9) a množstvom Mn akumulovaného v lístí jednotkových nadúrovňových stromov (2)
c) na plochách H–L (zakmenenie 0,3–0,7) a koncentráciou Mn v asimilačných orgánoch pri úrovňových stromoch (3),
d) na plochách H–C (zakmenenie 0,3–0,9) a hmotnosťou sušiny asimilačných orgánov úrovňových a podúrovňových stromov (4) a (6),
e) na plochách H–C (zakmenenie 0,3–0,9) a množstvom Mn akumulovaného v lístí jednotkových úrovňových stromov (5),
f) na plochách H–C (zakmenenie 0,3–0,9) a koncentráciou Fe v asimilačných orgánoch pri nadúrovňových stromoch (8),
g) na plochách H–C (zakmenenie 0,3–0,9) a množstvom Fe akumulovaného v lístí nadúrovňových, úrovňových a podúrovňových stromov (9), (10) a (12),
h) na plochách H–L (zakmenenie 0,3–0,7) a množstvom Fe akumulovaného v lístí jednotkových úrovňových a podúrovňových stromov (11) a (13).

V korunách nadúrovňových stromov hodnota Mn rástla s hustotou porastu v každej tretine koruny (obr. 1a). V tab. 2 sa tomuto trendu vymykajú hodnoty z plochy M. Čiastočne sa to dá vysvetliť tým, že sú to priemerné hodnoty za celú korunu, ale aj veľkou citlivosťou týchto meraní na miesto odberu. Pri úrovňových stromoch je tento trend opačný. Maximálne hodnoty sme zistili na vzorníku z plochy H s najsilnejším zásahom (obr. 1b). Táto postupnosť je čiastočne narušená výsledkami z plochy L, ktoré sú nižšie ako na kontrolnej ploche C (tab. 2). Pri podúrovňových stromoch nenachádzame závislosť koncentrácie Mn v listoch od sily ťažbového zásahu (obr. 1c). Vplyv tohto faktora je tu potlačený, ale nie je to kompetičnými vzťahmi s hlavnou úrovňou porastu. Aj keď tieto stromy majú menšiu nielen korunu, ale aj koreňový systém v porovnaní s vyššími stromovými triedami (Barna, Kodrík 2002), ich koncentrácia Mn je priemerná v porovnaní s vyššími stromami (tab. 1).

Koncentrácie Fe v porovnaní s Mn sú viac závislé od hustoty porastu. Tak ako pri nadúrovňových, aj pri úrovňových stromoch hodnoty Fe v listoch rastú so silou ťažbového zásahu vo všetkých tretinách koruny (horná, stredná, dolná – obr. 2a, b). U podúrovňových stromov sme nezistili závislosť od sily ťažby, maximálne hodnoty sú na ploche L a minimálne na M (tab. 4). To opäť dokazuje, že tieto stromy majú iné podmienky rastu ako horná úroveň (Barna 2004). Závislosť koncentrácie sledovaných prvkov od hustoty porastu možno vidieť aj v smere závislosti pri rovniciach (1) a (2) pri Mn (10) a (11) pri Fe. Korelačné koeficienty majú opačné znamienka.

Rozdielne podmienky rastu sa prejavujú aj v príjme mikroelementov Mn a Fe. Optimálny, vyššie uvedený pomer medzi Mn a Fe v rozsahu 1,5–2,5 (Kabata-Pendias, Pendias 1992) bol zaznamenaný len na ploche H pri úrovňových stromoch. V ostatných prípadoch jeho hodnota narastá. Najvyššia bola na ploche M pri nadúrovňových stromoch.

Koncentrácie mikroelementov sme číselne vyjadrili viacerými štatistickými charakteristikami. Z tab. 6 vidíme, že najväčšiu priemernú koncentráciu Mn mal porast na ploche H s najsilnejším zásahom a najnižšiu na ploche M so stredne silným zásahom. Hodnoty smerodajnej odchýlky nemajú jednoznačnú postupnosť s hustotou porastu. Variačný koeficient má rastúcu tendenciu s klesajúcou silou ťažbového zásahu. Pri hodnotách Fe tendencia rastu je opačná ako pri Mn. Minimálna priemerná hodnota je na kontrole (C) a maximálna na ploche H s najsilnejším zásahom, ale aj variabilita hodnôt bola na tejto ploche najväčšia. Aj variačný koeficient je najväčší na ploche H, ale neklesá s rastúcou hustotou porastu. Koeficientmi špicatosti a šikmosti sa testuje významnosť rozdielov analyzovaného rozdelenia od normálneho. Keďže všetky hodnoty sú v intervale (–2, +2), potom sa rozdelenia významne nelíšia od normálneho.

Corresponding author:

Ing. Ján Machava, Ph.D., Technická univerzita vo Zvolene, Lesnícka fakulta, T. G. Masaryka 24, 960 53 Zvolen, Slovenská republika
tel.: + 421 905 758 624, fax: + 421 455 332 654, e-mail: machava@vsld.tuzvo.sk