



**ANNUAL DYNAMICS OF K, CA AND MG CONTENT IN ORGANS OF BEECH IN THE BEECH ECOSYSTEM CALAMINTHO GRANDIFLORAE-FAGETUM IN MAVROVO NATIONAL PARK, MACEDONIA**

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annual dynamics,  
beech forest,  
potassium,  
calcium,  
magnesium,  
retranslocation

**SYNOPSIS**

Annual dynamics of K, Ca and Mg in the aboveground and belowground phytomass of six beech trees in the beech ecosystem *Calamintno grandiflorae-Fagetum* in Mavrovo National Park were investigated.

Potassium dynamics in some organs during the two consecutive investigated years showed different patterns. Highest concentrations and highest amplitudes were recorded in the most active organs: fine roots, twigs and leaves in contrast to the wood of stem, coarse roots and coarse branches. Retranslocation efficiency in leaves for K was 58.8%.

Very high concentrations of Ca were recorded in the bark of stem, branches and coarse roots with maximum of 3.5%. The concentration of calcium increased during the leaf senescence.

Magnesium concentration was highest in leaves as well as fine roots and twigs. The retranslocation efficiency of Mg in leaves was 37.5%.

**INTRODUCTION**

About 40 elements are considered as essential for living organisms (Duvigneaud & Denayer-De Smet 1971). The knowledge of their concentrations, quantities and dynamics in forest ecosystems is important since the annual mineral matter (nutrient) cycling intensity determines the productivity of forest ecosystems (Marinov et al. 1983). The intensity of plant-soil cycling depends on plant species composition, primary productivity

and soil chemistry (Mulev et al. 1994, 1995). Nutrient concentrations in different compartments of tree biomass are commonly used for evaluation of plant nutrient status, soil nutrient availability and as indicators of forest health (Hagen-Thorn et al. 2004)

Tree species in the forest ecosystems are main reservoirs of nutrients. They store huge amounts of minerals which surpass all of the other components in the forest ecosystems. Thus, the knowledge of nutrients' dynamics in living tree biomass is basic step in the study of mineral cycling in the forest ecosystems.

Nutrients' dynamics in trees depends on many ecological and physiological factors. Ecological factors are well known: availability of minerals in the soil (pedologic characteristics), climate (temperature, humidity, winds etc.), leaching by rain waters, phyllophagous and xylophagous activity, soil fauna impact on root systems, atmospheric pollution. Internal (physiological) factors are less known i.e. their mechanisms are not well defined. The retranslocation of minerals, vertical and horizontal transport in roots, stem and branches, allocation of minerals in perennial organs, exudation of roots and leaves are the most important physiological processes for explanation of nutrients' dynamics in living biomass. It is also very important to understand the structure of trees as systems consisted of repetitive semi-independent units (Ruohomäki et al. 1997).

The internal nutrient cycle of a tree is characterized by long distance transport and the large storage capacity of the trunk. This decreases its dependence of the current water and nutrient supply of the soil. The longevity of trees leads to an accumulation of foreign substances that can disturb physiological processes related to nutrient cycle (Glavac & Jocheim 1993).

The main goal of this study is to describe and quantify the annual dynamics of minerals (K, Ca, Mg) in the organs and tissues of beech trees in the forest ecosystem *Calamintho grandiflorae*-Fagetum in Mavrovo National Park. The annual dynamics was studied in two consecutive years in both aboveground and belowground parts of the ecosystem. Furthermore, seasonal fluctuations and retranslocation intensity of minerals was defined.

## STUDY SITE

Presented work was conducted in the frames of the project "Complex ecosystem investigation in stationary conditions in the beech ecosystem *Calamintho grandiflorae*-Fagetum in Mavrovo National Park" (Grupče & Melovski 1999). Stationary (20°48' E, 41°42' N) is situated in well-developed middle aged beech forest on Bistra Mt., village Leunovo dystric, near Mavrovo Lake at the elevation of 1400 m. The community is developing on dystric cambisole soil type (Tab. 1). Climate is mountain-continental with Mediterranean influence (Filipovski et al. 1996).

**Tab. 1 Soil properties in the investigated beech ecosystem****a) Physical properties and soil pH**

horizon	depth	Water retention capacity	Hygroscopic moisture	Porosity	Air capacity	Coarse sand	Fine sand	Silt	Clay	Skeleton	Real density	Bulk density	pH (H <sub>2</sub> O)	pH (KCl)
	[cm]	%	%	%	%	%	%	%	%	%	g·cm <sup>-3</sup>	g·cm <sup>-3</sup>		
A0 <sub>f/h</sub>	5-10	48.97	5.24	76.55	27.58	11.95	41.25	35.75	11.05	0		0.54	5.80	5.38
A1	10-25	40.54	2.88	61.49	20.95	20.55	20.80	42.40	16.25	25.23	2.64	1.02	5.25	4.68
B	25-60	35.24	2.12	56.58	21.34	17.03	27.55	41.07	14.35	33.09	2.72	1.18	5.02	4.52
(B)C	60-80	32.69	1.47	47.46	14.77	22.00	33.60	34.25	10.15	38.73	2.65	1.39	5.01	4.48
C	80-120	31.79	1.31	42.61	10.82	24.75	32.45	33.95	8.85	48.07	2.73	1.57	4.93	4.40

**b) Chemical properties of the soil**

Horizon	depth [cm]	humus	N	P	K	Ca	Mg	Fe	Na	Mn	Zn	Cu	Pb	Cd	Co
			%								mg·kg <sup>-1</sup>				
A0 f/h	5-10	10.28	1.541	0.038	1.50	0.030	0.38	1.56	0.034	0.060	104.2	12.75	9.46	1.35	7.69
A1	10-25	3.22	0.560	0.024	1.50	0.003	0.36	2.39	0.043	0.046	110.4	22.09	8.81	0.92	9.08
B	25-60	1.74	0.255	0.016	1.41	0.002	0.33	1.99	0.035	0.030	84.9	18.85	3.58	0.77	8.13
(B)C	60-80	0.97	0.207	0.015	1.39	0.002	0.35	2.39	0.041	0.025	83.4	19.88	3.90	0.78	8.03
C	80-120	0.81	0.197	0.017	1.22	0.002	0.31	2.24	0.041	0.028	95.5	21.90	6.61	0.96	7.89

Data according to Lazarevski (1993) based on the measurements of meteorological station Mavrovo (1240 m), show that the average annual temperature is 7.1 °C. The minimal average monthly temperature (below 0 °C) is registered during three winter months with minimum of -2.2 °C. The mean monthly maximal temperatures are measured in July (16.3 °C) and August (16.0 °C). The mean autumn temperature (8.2 °C) is higher than the spring one (5.8 °C). The mean annual fluctuation of temperature is 18.7 °C.

The mean annual precipitation is 1103 mm. It consists mainly of snow and smaller amounts of rain in the warmer periods of year. From October to March there is over 100 mm precipitation per month, April, May are characterised by 80-100 mm, and July and August have less than 50 mm monthly precipitation. Permanent snow cover lasts 30-110 days while the snow period is 166 days in average.

Beech (*Fagus sylvatica*) absolutely dominates in the investigation locality with a density of 1200 trees · ha<sup>-1</sup>. Mean DBH of trees is about 16 cm. Shrub layer is represented mainly by beech and shrubs of fir (*Abies borisii-regis*). Herb layer in the investigation site has low biomass (less than 6 kg·ha<sup>-1</sup>). The most abundant herb species are *Anemone nemorosa*, *Dentaria bulbifera*, *Carex sp.*, *Brachipodium sylvaticum*, *Asperula odorata*, *Rubus sp.*, *Actaea spicata*, *Pteridium aquilinum* etc. Aboveground annual litter fall biomass is 4.98 t·ha<sup>-1</sup> while the average forest floor mass is 20.58 t·ha<sup>-1</sup>.

## METHODS

Annual dynamics of K, Ca and Mg in the aboveground and belowground phytomass of beech trees in the beech ecosystem *Calamintho grandiflorae*-Fagetum in Mavrovo National Park were investigated. Three beech trees were chosen in 1998 and other three in 1999. Selected trees were representatives of the tree layers in the ecosystem: dominant, subdominant and suppressed trees.

The samples were collected in every two months. The following organs and fractions were analyzed: stems (bark and wood from two depths: 0-30 mm and 30-50 mm depth), coarse roots (5-15, 15-30 and over 30 mm), branches (5-15 and 15-30 mm), fine roots (with diameters less than 0.5, 0.5-1 and 1-5 mm), twigs (1-, 2- and 3-years old, short shoots and older twigs), leaves, buds and beech acorns. Bark and wood of coarse roots and coarse branches was analyzed separately.

Plant material was grinded in electric mill and dried at 105 °C for 24 hours. The determination of K, Ca and Mg content was done according to Allen ed. (1989). About 1 g of dried material was wet digested in HNO<sub>3</sub>, HClO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub> mixture in volume ratio 10:2:1. The concentration of minerals was measured by atomic absorption spectrometry on Varian AAS 10BQ.

Retranslocation efficiency in leaves was estimated by calculation of retranslocation percentage (RT) according to the following formula (Escudero et al. 1992):

$$RT = \frac{M_f - M_o}{M_f} \cdot 100$$

where, M<sub>f</sub> in maximum nutrient pool size, M<sub>o</sub> nutrients in leaf-fall (leaf-fall data were taken from Melovski et al. (1999a) and unpublished data).

Residence time (T) was calculated as:  $T = \frac{M_f}{M_o}$

## RESULTS

### Potassium (K)

K content dynamics in small roots (<0.5 mm) had different pattern in 1998 and 1999. (Fig. 1). Continuous increase from spring towards winter was recorded during 1998. Opposite trend was observed in 1999. Other root fractions had irregular K dynamics (Fig. 1). K content in these roots varied between 0.2 and 0.4%.

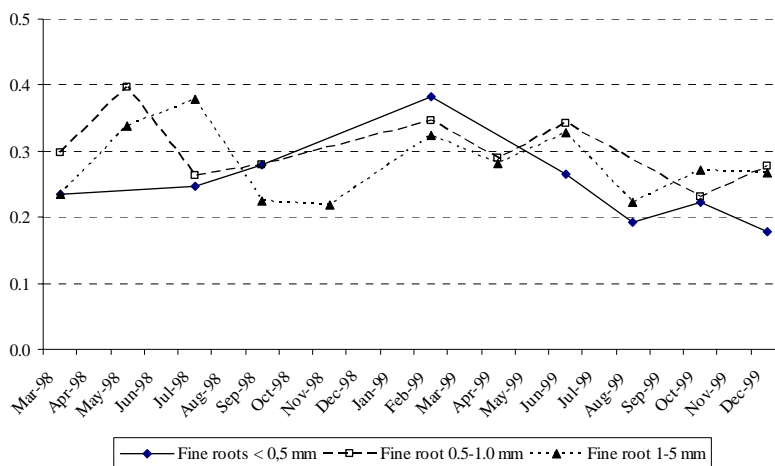


Fig. 1 Dynamics of K content (%) in roots <5 mm in 1998 and 1999 (average values of the three analyzed trees)

K content in the roots of diameter larger than 5 mm showed low amplitudes during the two investigation years (Fig. 2). K content in the wood of roots with diameter 5-15 mm was continuously higher than the one in the wood of large roots (15-30 mm). Coarse roots' bark had irregular dynamics with some pronounced peaks (Fig. 2).

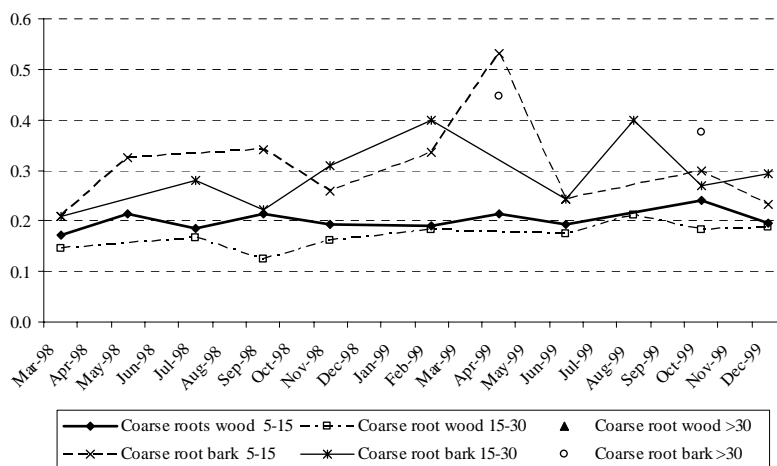


Fig. 2 Dynamics of K content (%) in roots >5 mm in 1998 and 1999 (average values of the three analyzed trees)

K content in the stem wood up to 30 mm depth showed small seasonal variations although there was minor autumn increase and spring decrease. The stem wood deeper

than 30 mm had opposite dynamics. The dynamics in the stem bark had similar pattern (spring decrease and autumn increase), but with smaller amplitudes (Fig. 3).

The 1-year-old twigs showed increase of the K content during the spring period in 1998 (Fig. 4). Generally, the values of K content in twigs were lowest during the winter period (Fig. 4).

Similar pattern was observed in coarse branches (Fig. 5): maximum during the spring'98 and steady values during 1999.

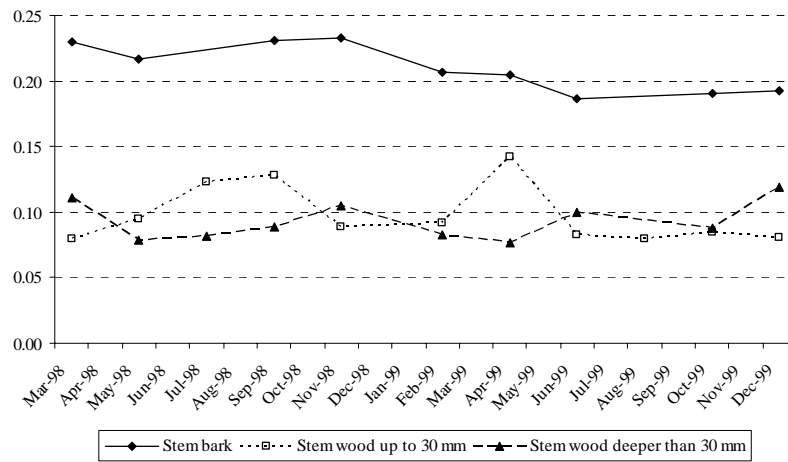


Fig. 3 Dynamics of K content in bark and wood of stem in 1998 and 1999 (average values of the three analyzed trees)

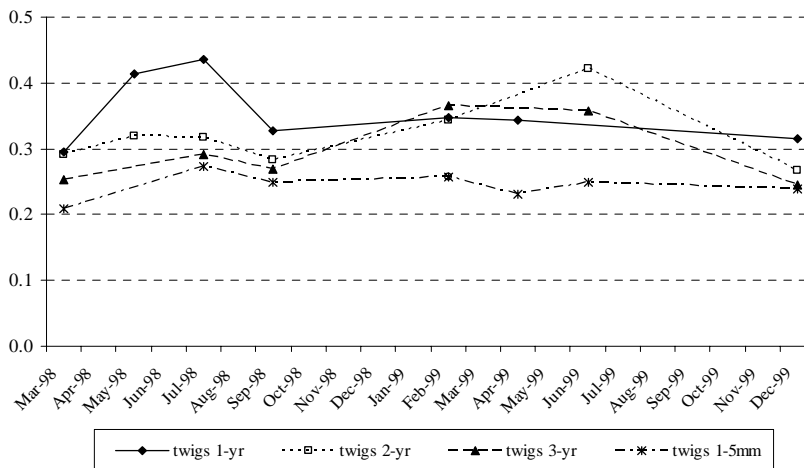


Fig. 4 Dynamics of K content (%) in twigs in 1998 and 1999 (average values of the three analyzed trees)

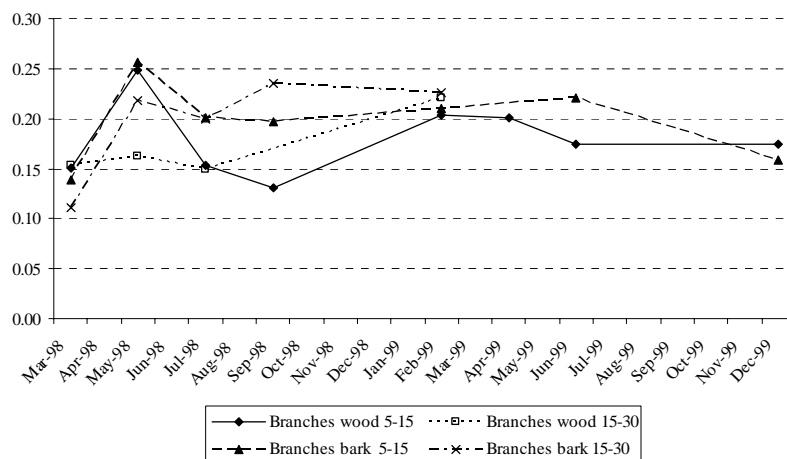


Fig. 5 Dynamics of K content (%) in bark and wood of branches in 1998 and 1999 (average values of the three analyzed trees)

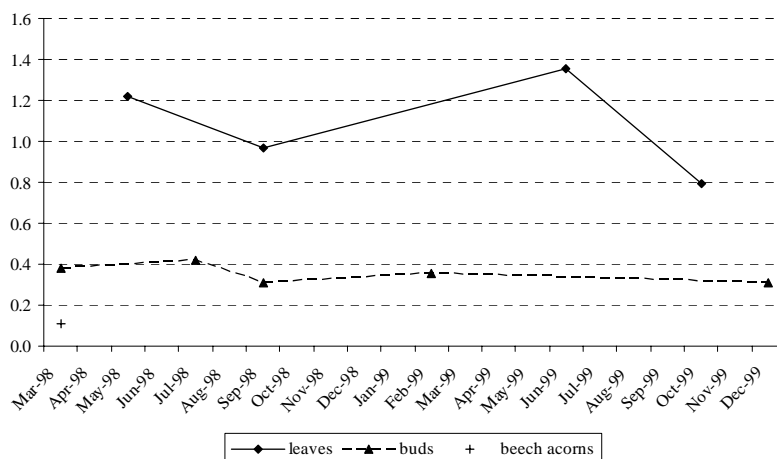


Fig. 6 Dynamics of K content (%) in roots, leaves, buds and beech acorns in 1998 and 1999 (average values of the three analyzed trees)

Leaves had a tendency for decrease of the K content values from spring/summer period towards autumn (Fig. 6). K content in buds had steady values during the investigation period.

### Calcium (Ca)

Ca content in fine roots (<1mm) had maximal value in August'99 (2.57%) and minimal in September'98 (1.06%). Minimal Ca content in roots of 1-5 mm diameter was recorded in July'98 (0.19%) and maximal one in May'98 (1.74%). The Ca content in the wood of coarser roots (5-15 and 15-30 mm) showed little variation (Fig. 8)

The total Ca content in root bark was higher than the one in the wood. Maximal values in the bark were recorded in November'98 to February'99 (2.89%); minimal values in June'99 (1.44%) and the average value was 1.58% (Fig. 8).

Ca content was higher in the stem bark than in the stem wood, as well (Fig. 9). The content in bark showed high amplitudes and varied between 0.25 and 3.5%.

Twigs had high Ca content that fluctuated between 0.8 and 3.6%. Greatest amplitudes were recorded in 1-year-old and 2-year-old twigs (Fig. 10).

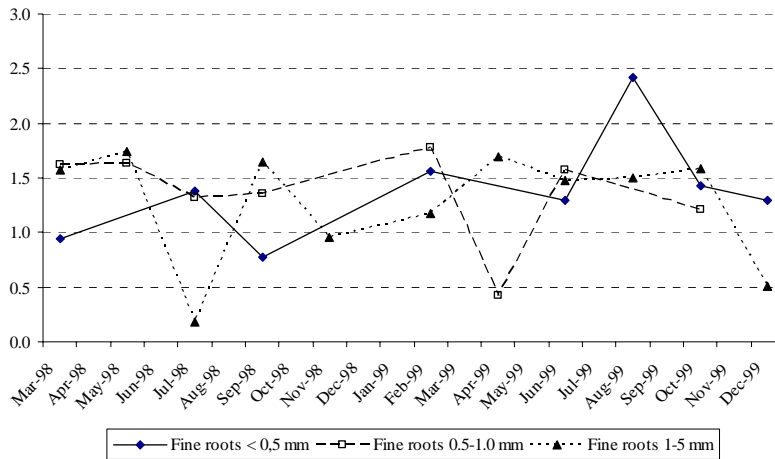


Fig. 7 Dynamics of Ca content (%) in roots <5 mm in 1998 and 1999 (average values of the three analyzed trees)

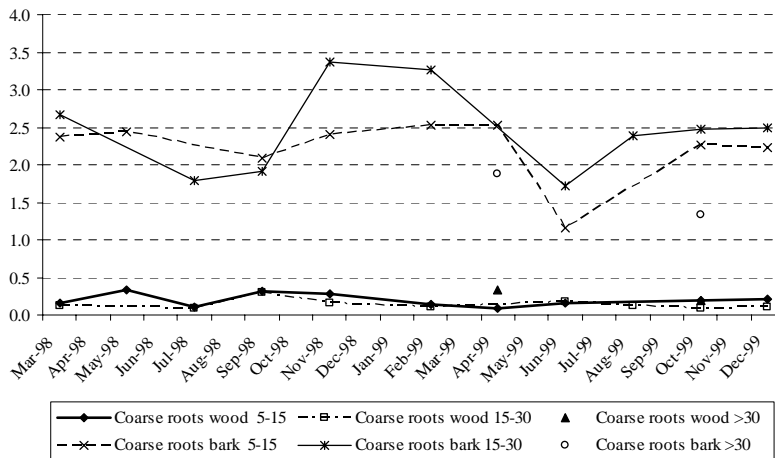


Fig. 8 Dynamics of Ca content (%) in roots >5 mm in 1998 and 1999 (average values of the three analyzed trees)

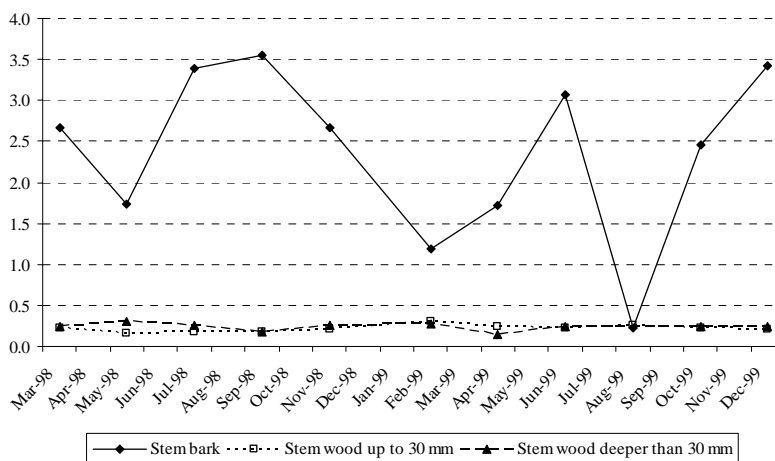


Fig. 9 Dynamics of Ca content in bark and wood of stem in 1998 and 1999 (average values of the three analyzed trees)

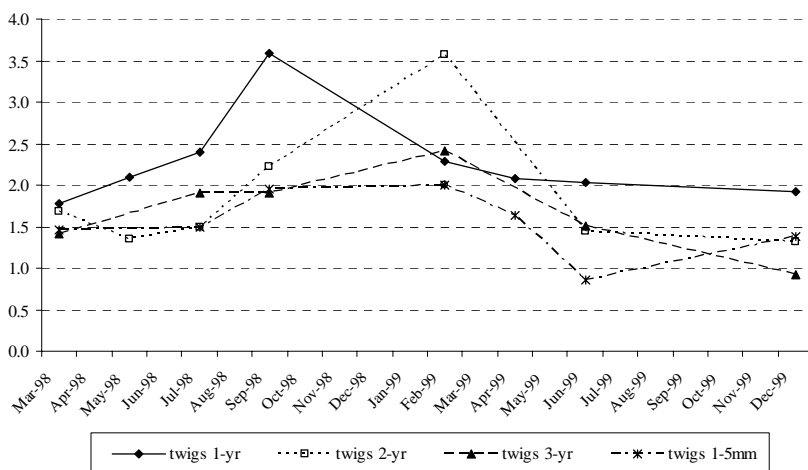


Fig. 10 Dynamics of Ca content (%) in twigs in 1998 and 1999 (average values of the three analyzed trees)

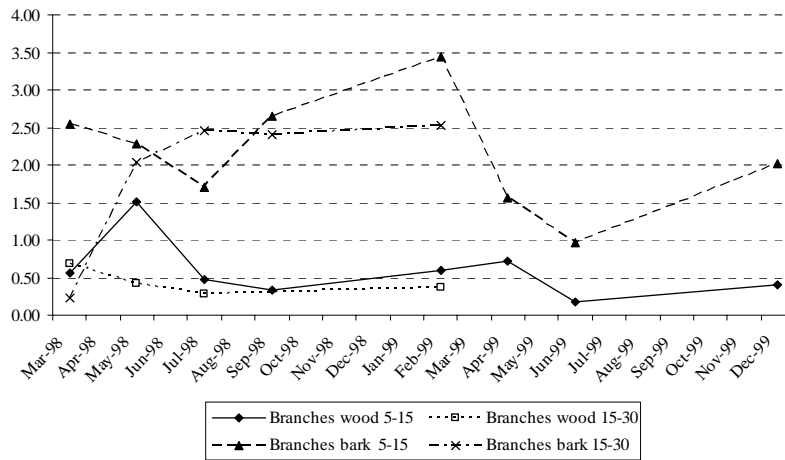


Fig. 11 Dynamics of Ca content (%) in bark and wood of branches in 1998 and 1999 (average values of the three analyzed trees)

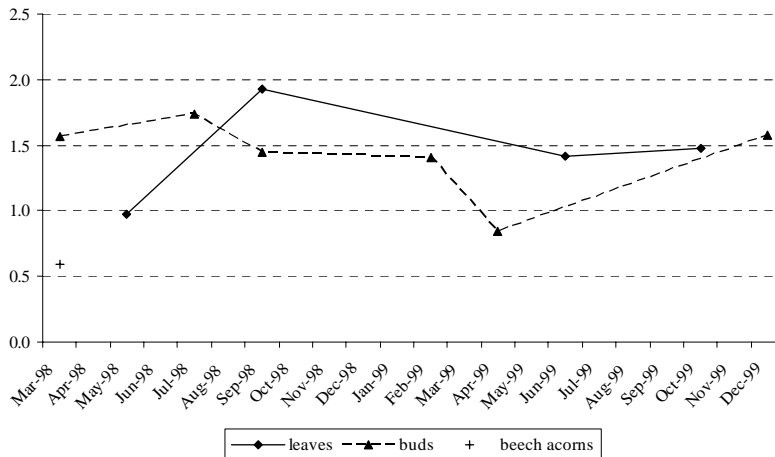


Fig. 12 Dynamics of Ca content (%) in roots, leaves, buds and beech acorns in 1998 and 1999 (average values of the three analyzed trees)

Ca content in bark of stem and coarse branches was higher than the one in the wood of these organs. Minimal Ca content in the bark of branches was recorded in June'99 and maximal in February'99 (Fig. 11). The dynamics of Ca content in the wood of branches showed steady pattern with average values of 0.51% (Fig. 11)

Ca content in leaves increased from spring to autumn in 1998 and 1999. The increase was more pronounced in 1998 than in 1999 (Fig. 12). The content in buds had maximum in July'98 (1.74%) and ± steady values in the rest of the investigated months. The content in beech acorns in March'98 was 0.595% (Fig. 12).

### Magnesium (Mg)

High values for Mg content in wood of coarse roots (5-30 mm), stem bark, stem wood (Fig. 10) were not taken into account for calculation of average annual values (Tab. 2).

The dynamics of Mg content in fine roots is presented on Fig. 13. Maximal values for Mg content in fine roots (1-5 mm) were registered in May'98 (0.093%) and June'99 (0.102%). Minimal value was recorded in December'99 (0.013%).

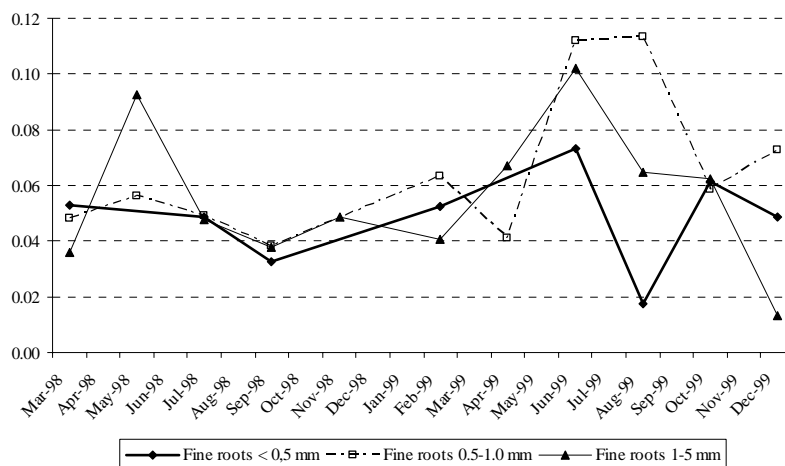


Fig. 13 Dynamics of Mg content (%) in roots <5 mm in 1998 and 1999 (average values of the three analyzed trees)

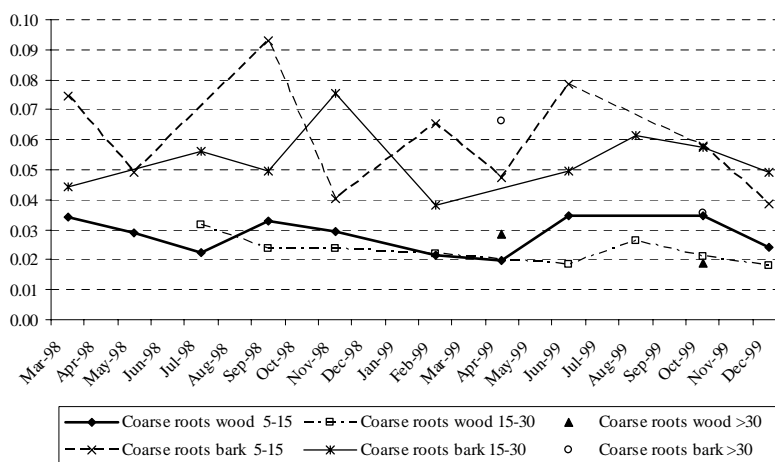


Fig. 14 Dynamics of Mg content (%) in roots >5 mm in 1998 and 1999 (average values of the three analyzed trees)

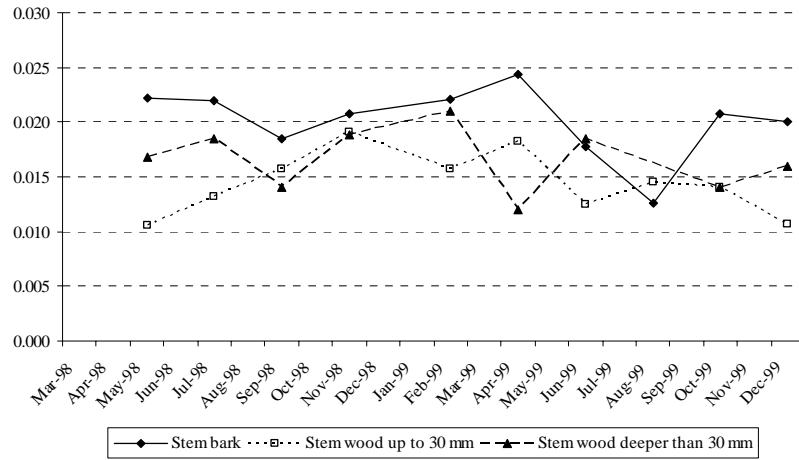


Fig. 15 Dynamics of Mg content in bark and wood of stem in 1998 and 1999 (average values of the three analyzed trees)

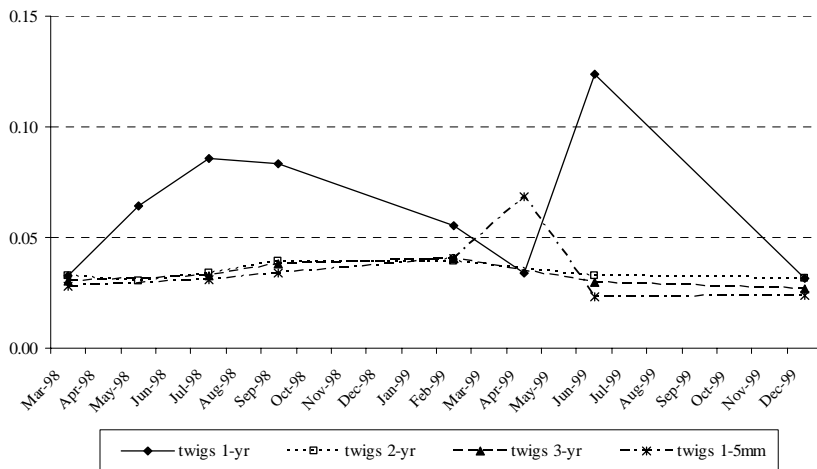


Fig. 16 Dynamics of Mg content (%) in twigs in 1998 and 1999 (average values of the three analyzed trees)

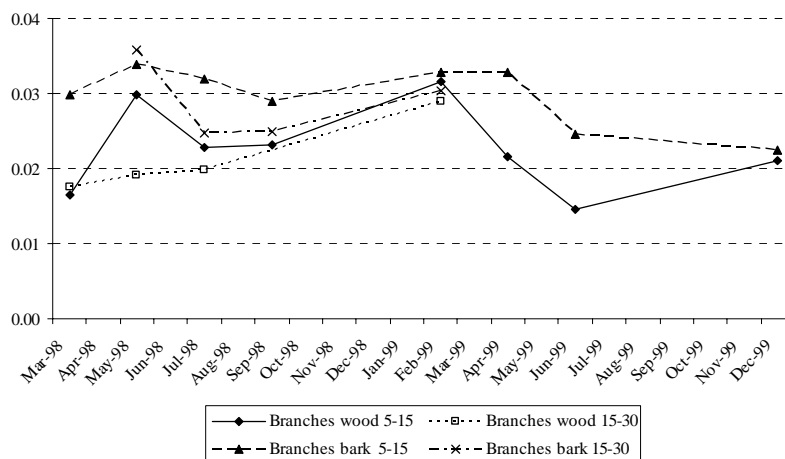


Fig. 17 Dynamics of Mg content (%) in bark and wood of branches in 1998 and 1999 (average values of the three analyzed trees)

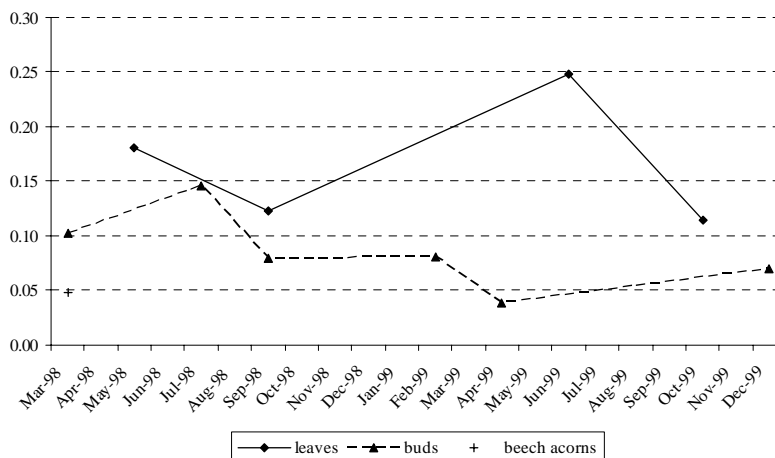


Fig. 18 Dynamics of Mg content (%) in roots, leaves, buds and beech acorns in 1998 and 1999 (average values of the three analyzed trees)

The content in bark of coarse roots was higher than the one in the wood of these roots (Fig. 14).

Mg content dynamics in bark and wood of stem and coarse branches showed steady pattern with little variation (Fig. 15). Twigs had higher Mg content than in the coarser branches, both wood and bark (Fig. 16 and 17).

Bark and wood of coarse branches had higher Mg contents during winter and early spring and lowest values during summer (Fig. 17).

There was clear decrease of Mg content in leaves from spring to autumn (Fig. 18). The highest content in buds was recorded in July'98 (0.15%). The Mg content in beech acorns in March'98 was 0.05%.

## DISCUSSION

### Average values

Data presented on Fig. 1-18 were used to calculate the average annual values of K, Ca and Mg (Tab. 2). The values are comparable to other studies on European beech (Hristovski 2007). The only exception is Ca that has very high contents in bark, fine roots, twigs and leaves. However, such values have been registered in some forest ecosystems (Johnson & Risser 1974; Jönsson 2000)

Tab. 2 Average values for content of K, Ca and Mg (%) in the organs and fraction of investigated beech trees for during the investigation period (1998 and 1999)

Nutrient	Fine roots			Coarse roots						Stem		Twigs					Branches				leaves	Buds	Beech acorns	
	<0.5 mm	05.-1.0 mm	1-5 mm	Wood			Bark			Bark	Wood		1-yr	2-yr	3-yr	Short shoots	1-5 mm	Wood		Bark				
				5-15	15-30	>30	5-15	15-30	>30		Up to 30 mm	Deeper than 30 mm						5-15 mm	15-30 mm	5-15 mm				15-30 mm
<b>K</b>	0.25	0.33	0.28	0.20	0.17	0.17	0.31	0.29	0.41	0.21	0.10	0.09	0.44	0.32	0.30	0.26	0.24	0.18	0.17	0.19	0.20	1.08	0.44	0.11
<b>Ca</b>	1.39	1.64	1.28	0.20	0.14	0.14	2.22	2.45	1.60	2.37	0.22	0.24	2.27	1.87	1.68	2.00	1.54	0.59	0.44	2.15	1.93	1.45	1.43	0.60
<b>Mg</b>	0.048	0.065	0.056	0.028	0.046	0.046	0.061	0.053	0.051	0.039	0.027	0.033	0.064	0.034	0.033	0.041	0.036	0.023	0.021	0.030	0.059	0.167	0.086	0.049

### Seasonal dynamics of K, Ca and Mg

Chemical composition of plant depends on the physiological role of the elements independently from the availability of elements in the soil. In this case, the geochemical environment is not a limiting factor since the plants have developed mechanisms for regulation of the acquirement and accumulation of certain elements (Mulev et al. 1995; Augusto et al. 2000). Thus, the absorbed quantity of nutrients is determined by the physiological processes i.e. the role of nutrients in photosynthesis, cell construction, nutrients exchange (Ivlev 1986 in: Mulev et al. 1995). As a result, the nutrient content in organs and whole plants changes during plant development and shows seasonal variations. There are only few studies which have shown direct correlation between soil availability and plant nutrient content. According to (Albert & Pescoller-Tiefenthaler 1992) such correlation exists for Ca and Mg in the case of beech leaves. Soil Ca content in our investigation (Tab. 1) was low while the content in leaves was exceptionally high (Fig. 7-

12, Tab. 2). These data probably do not support the positive correlation between soil availability and leaf content, rather they suggest to more complex relationship.

K content in leaves decreased from spring to autumn as a result of retranslocation by active resorption from old leaves to perennial tissues (Chapin 1980 in Escarré et al. 1999). K content in xylem sap of beech shows highest values during the autumn. In spring, as opposite to Ca and Mg, the values are slightly higher than in the rest of the year (Glavac et al. 1990). Our investigation suggests that the K content in perennial tissues is higher during the active vegetation period and decreases in autumn.

Ca content shows high variation in values, especially in the bark of coarse roots, coarse branches and stem. According to Denaeyer-De Smet (1971) the variation of Ca is more expressed than for other nutrient. The underlying cause might be the easy leaching of Ca by the rainwater. Glavac et al. (1990) reported highest values for Ca content in xylem sap during spring and lowest in late summer.

Mg has similar dynamics as Ca: highest values in the xylem sap during spring, and lowest in later summer (Glavac et al. 1990). This pattern was supported by our investigation, as well.

### Retranslocation

Retranslocation is very important in the research of forest ecology since it shows the nutrient economy. It indicates the translocation of labile components of certain nutrient from old leaves to perennial tissues. However, plants have efficient retranslocation only in the case if the benefits of this process are gained without significant costs. In deciduous species (with leaves that live one year), retranslocation is the major factor that controls the residence time of nutrients, although the extended life of leaves can have certain influence (Escudero et al. 1992).

Tab. 2 Retranslocation efficiency and residence time for K, Ca and Mg in leaves

	K	Ca	Mg
Content in young leaves <sup>1</sup>	1,29	1,19	0,21
Content in senescent leaves <sup>2</sup>	0,88	1,70	0,12
Content in the leaves of the litter-fall <sup>3</sup>	0,35	3,21	0,12
Quantity in live leaves <sup>4</sup>	45,67	42,36	7,63
Quantity in leaf litter-fall <sup>4</sup>	18,80	113,65	4,77
RT (%)	58,8	-168,3	37,5
Residence time (years)	2,43	0,37	1,60

<sup>1</sup> Average value for May'98 and June'99.

<sup>2</sup> Average value for September'98 and October'99

<sup>3</sup> According to M e l o v s k i et al. (1999a) and unpublished data

<sup>4</sup> Unpublished data

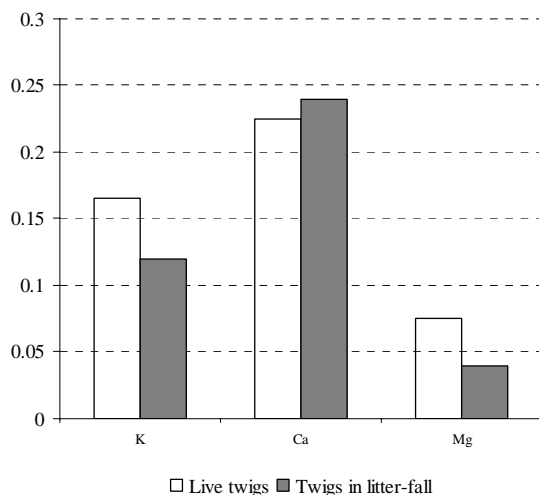
Retranslocation efficiency is evolutionary mechanism. In the ecosystems poor in nutrients, the plant species with efficient retranslocation have advantage to other species. It seems that the retranslocation is characteristic of certain species and populations and shows little changes in different nutrient availability and depends on the efficiency of phloem transport (Aerts 1996). However, efficiency of retranslocation can decrease when nutrient is available in sufficient amount (Kobe et al. 2005).

K has high retranslocation efficiency (Eschrich et al. 1988). According to our results, K had the highest retranslocation coefficient, even higher than the one for nitrogen (Hristovski et al. in litt.). However, the RT for K (Tab. 3) is probably higher than the real value since K is easily leachable from old leaves (Whittaker et al. 1979; Chapin & Kedrowski 1983).

RT for Mg was high (37.5%). The mechanism of Mg retranslocation was described by Eschrich et al. (1988). During leaf senescence Mg is released from decomposed chlorophyll as free Mg ions. These are transported by the sieve elements of leaf rachis to the stem. Mg is stored in the stem in life cells of the heartwood, radial rays and cells of the outermost rings.

Ca content in leaves increased during the leaf senescence. The process of accumulation of Ca dead tissues continues during the process of litter decomposition (Melovski et al. 1999b; Hristovski 2004). There was no net retranslocation of Ca although small part of Ca can be transported from leaves into the perennial tissues through some unknown mechanisms (Eschrich et al. 1988). Underlying cause for Ca accumulation on aged leaves is its low mobility since it is found in the form of calcium oxalate in the beech leaves (Albert & Pescoller-Tiefenthaler 1992).

Chemical elements that can be retranslocated are Mg, Cu, K, Na и P while Ca, Cd, Co, Fe, Mn, Pb, Zn increase their content in ageing leaves (Fromm et al. 1977; Albert & Pescoller-Tiefenthaler 1992; Tyler 2005). According to Eschrich et al. (1988) only Mn, Fe, Pb and Zn are actively transported from the stem into the old leaves.



**Fig. 19. Comparison of the content of K, Ca and Mg (%) in live twigs and twigs in the litter-fall.**

Retranslocation has been observed in twigs, as well, but with lower efficiency than in leaves (Whittaker et al. 1979). The data obtained during our investigation could not be used to estimate the retranslocation in twigs and branches. Thus, Fig. 19 shows that content of K, Ca and Mg in live twigs (obtained in this study) and dead twigs in the litter (Melovski et al. 1999a; unpublished data). This analysis indicates that K and Mg are subject of retranslocation in twigs which is opposite to Ca.

## CONCLUSIONS

Highest values of nutrient contents were recorded in the physiologically most active organs (leaves, twigs and fine roots). This indicates the economy of ecosystems for this nutrients (N, P, K, Mg). This is sustained by the low content of these nutrients in inactive organs (wood of stem, coarse roots and coarse branches) and high content in organs involved in photosynthesis, water absorption and transportation. High values of nutrients were registered in bark which serves as a reservoir of nutrients.

Trees save nutrients by their translocation from heartwood to outermost parts of the wood and by their retranslocation from leaves, twigs and fine roots.

The content of nutrients was higher in 1999 than in 1998 which is probably due to the impact of climatic factors.

RT for K and Mg was 58.8 and 37.5%, respectively. RT for Ca showed negative values indicating its increase in ageing leaves.

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