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VARIABILITY OF NUTRITIVE MACROELEMENTS IN PEDUNCULATE OAK (*Quercus robur* L.) LEAVES IN SERBIA

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Nowadays, the territory of pedunculate oak (*Quercus robur* L.) in Serbia is less widespread than in the past, primarily as the consequence of excessive exploitation and aggravated regeneration caused by the changed groundwater regime. The researches in this paper were aimed at the analysis of the variability of the content of macroelements in leaves, as well as of the

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soil characteristics in the pedunculate oak populations on the different sites, according to which the sites with the best conditions for the nutrition of pedunculate oak would be singled out. The analysed populations are of natural or artificial origin, and they occurred during the process of restitution. They are situated in the zone ranging from continental to moderate continental climate, at five different localities and five different types of soil. Foliar analyses of 150 individual - trees of pedunculate oak at five sites in Serbia and the respective soil analysis show that individual variability in macroelements among trees was not statistically significant, while the site effect was highly significant. Concentrations of elements, at all sites, in the decrease sequence were: N>Ca>K>Mg>P>Na. The highest individual variability was exhibited by Na, followed by Mg, Ca and K, and P as well as N had the lowest variability. The obtained results point to the conclusion that the variability of the content of macroelements in leaves is mainly the result of the environmental influence. Statistically significant intra-individual variability, as an indicator of the existence of genetic differences between trees within populations, was detected only for Ca concentration in leaves.

Key words: individual and population variability, leaf, macroelements, *Quercus robur*, soil

INTRODUCTION

Pedunculate oak occurs almost throughout Europe, with the exception of Spain and central Portugal. Ecologically, it is a very plastic species, adapted to both continental - forest and forest - steppe climate, and to Sub Mediterranean and Mediterranean climate in its southern range. Regarding the adaptability to soil conditions, pedunculate oak does not thrive on shallow and dry soil and requires deep and fertile soils affected by groundwater and occasionally flooded. Pedunculate oak polymorphism is the consequence of its wide range, spontaneous hybridisation within the genus *Quercus*, introgression and intraspecific variability, which makes its determination more difficult. There are also a great number of lower systematic categories of pedunculate oak (GAJIC *et al*. 1982; GAJIC and TESIC 1992) in Serbia. Pedunculate oak is widely distributed in Serbia, especially in Vojvodina, Macva and Pomoravlje. The best pedunculate oak forests in Serbia are in the valley of the river Sava and its tributaries, on the alluvial, fertile sandy - loamy or clayey soil, on the land with relatively high groundwater level and also occasionally flooded, but without stagnating water during the growing season (JOVANOVIC, 1971). Pedunculate oak forests are a permanent community conditioned by edaphic factors. Pedunculate oak is the edificator species of Serbian forest of pedunculate oak and ash: *Querceto - Fraxinetum serbicum mixtum* Jov. 1951. (JOVANOVIC, 1971; RAUS, 1976; TOMIC, 2004). The area of pedunculate oak forests in Serbia was considerably reduced during the 20th century by overfelling for highly evaluated wood, but also by forest decline due to the changes of groundwater regime (KOVACEVIC and ORLOVIC 2007). The lowering of groundwater level was caused by water supply projects, construction of drainage systems and embankments along the river banks, as well as by the global climate change. Pedunculate oak is a species with deep roots and adult trees can reach the groundwater level, which makes them survive even in the areas with lower groundwater level. However, the changed site conditions in pedunculate oak forests often prevent their natural regeneration. This means that, in the new environmental conditions, the existing pedunculate oak forests do not represent the natural potential vegetation of the given sites, but only the sites inherited from the times when site conditions were different. The state of nutrition and growth of forest trees are one of the main indicators of habitat quality and effective soil fertility. Forest tree nutrition depends on site conditions. For example, beech in different site conditions in Serbia shows very large differences in content of nitrogen in leaves (MILETIC *et al.,* 2005). Among the entire group of site conditions, it is the properties of soil that bear an enormous impact on nutrition of forest trees. Therefore, on reclaimed mine soils of various mineralogical composition, under equal climatic conditions, different concentrations of nutrition macro-elements were found in the leaves of Douglas fir, Silver Lime, Common Alder, Japanese Larch, Black Locust, Austrian Pine, and Scots Pine (MILETIC, 2004). In addition to the various site conditions uptake of nutrients from the soil depends on genetic characteristic of trees. Thus, different provenance of the same species in the same site condition uptake different amounts of nutrients (LAVADINOVIC *et al.,* 2010). The optimal amount of nutrients and their ratios in plants are the base of successful growth and development, total production potential, as well as plant resistance to biotic and biotic agents. Insect growth and development depend on nutritive value and secondary metabolite content of their host plants (MILANOVIC *et al.,* 2008). Nutrient uptake from the soil is important for plant development and it depends largely on the complex mechanism of uptake regulation (TREMOLIERES *et al.* 1999; COVELO *et al.* 2008). Plants accumulate nutrients in all organs, the highest concentration being in the assimilation organs, i.e. in the leaves. Leaf is a plant organ very sensitive to environmental changes, which are reflected in its morphological, structural and physiological changes. Therefore, leaves can be applied in the analysis of the genetic and environmental variability. Few researchers deal with individual foliar variability, but all of them emphasise its significance (CHARLES and GARTEN 1976; NIKOLIC and ORLOVIC 2001; GALLARDO and COVELO 2005; NIKOLIC *et al.* 2006). Investigation of oak in Serbia has the most in the field of systematic, breeding and production forests (JOVANCEVIC, 1966; JOVANOVIC, 1971; ERDESI, 1985; GAJIC and TESIC, 1992; NIKOLIC *et al.,* 2006; BOBINAC, 2007; KOVACEVIC and ORLOVIC, 2007). Recently, both the current research in the field of secondary metabolites (RAKIC *et al.,* 2006; RAKIC *et al*., 2007) and anatomy (BATOS *et al*., 2006). The results presented here show the first research study of nutrition in natural populations of oak (BATOS, 2010; BATOS *et al.,* 2010).

The aim of the paper was to determine which of the analysed sites are most favourable for the nutrition of pedunculate oak, based on the content of macroelements in leaves, as well as on the soil characteristics. In Serbia, a more in –

comprehensive study of pedunculate oak from this aspect has not been performed to date.

MATERIALS AND METHODS

The researches in the paper refer to the analysis of 6 elements (N, P, K, Ca, Mg, Na), in leaves of 150 pedunculate oak trees (29 - 31 per a site), as well as of the soil characteristics, from five sites in Serbia. The analyzed trees are situated in the natural populations of the mixed origin (generative and vegetative) on the sites Sombor and Vrsac, or in the artificially established stands (of generative origin) on the sites Ada Ciganlija, Bojchinska suma and Subotica. The studied stands originate from different periods, and the age of individual trees ranged from 60 to 130 years. In regard of its position and characteristics, the analyzed trees are the representatives of the populations from which they were singled out. The trees of the similar age, of high increment and satisfactory health condition, were taken for the analysis from each locality.

Site characteristics

The selection of the sites was based on the principle of the selection of areas on which pedunculate oak is dominant, and which differ by the site conditions. Five localities, at which pedunculate oak is located on the site which is ecologically favourable for it, two in the vicinity of Belgrade (Ada Ciganlija, Bojcinska suma), and three in Vojvodina (Sombor, Subotica, Vrsac), were selected. These regions are characterized by the continental or moderate continental climate, with the mean annual temperature from 10.6 ° C - 11.8° C, with mean annual precipitation ranging from 555 mm - 691 mm, and altitude ranging from 70 m - 137 m (Table 1). The distance between the neighboring sites, from South to North, and from West to East, is the following: Bojcinska suma - Ada Ciganlija - Sombor - Subotica - Vrsac; 30 – 170 – 84 - 250 km, respectively.

The site Ada Ciganlija is situated on the river island of the same name in the riparian area of the river Sava in Belgrade. By its plant - geographical position, it is the boundary of the Pannonian and the Moesian Provinces. The dominant forest is Ass. *Quercetum farnetto - cerris* Rud. 1949. Soil type at the analyzed site is fluvisol calcaric. The conditions of pedunculate oak development in this area are significantly changed last decades. Flooding is controlled by the construction of embankments along the island, which also prevents the recurring inflow and outflow of river sediment. The pedogenetic processes in the surface part of the solum have acquired the terrestrial character.

The site Bojcinska suma is located in the immediate vicinity of Belgrade. In this area, pedunculate oak is actually the last remnant of the old marsh - lowland pedunculate oak forests, which were in the past widely distributed in this part of the Sava riparian area. This is a belt of alluvial-hygrophilous forests *Carpino - Quercetum roboris* Raus. 1969. The soil type at the studied site is planosol dystric characterised by extended stagnation of gravitational water in the profile.

The site Sombor is a part of the Gornje Podunavlje (Upper Danube Basin) forest area, in the West part of Serbia and the South part of the Pannonian Plain. The analysed pedunculate oak population belongs to Ass. *Carpino betuli - Quercetum roboris* Anic. 1959. The determined soil type at the studied site is gleysol calcaric.
The site Subotica is the South part of the Suboticko - Horgoska Pescara and is located in the northern part of Serbia. From the coeno - ecological aspect, it is Ass. *Quercetum roboris* Jov. et Tom. 1979. The determined soil type is arenosol calcaric.

Table 1: General characteristics of the five Quercus robur L. sites analyzed selected for the study.

Site	Coordinates of site	Altitude m	Association	Agge	Analyzed area	Mean annual temperature	Mean annual precipitation	Parent material	Soil	* Lang's rain factor
Ada Ciganlija	44° 48´ N 20° 24´ I	70 - 76	*Quercetum farnetto-cerris* Rud. 1949.	60	1.0 ha	11.8° C	654 mm	Sandy sediments	Fluvisol calcaric	55 Humid
Bojcinska šuma	44° 43´ N 20° 10´ I	77 - 78	*Carpino-Quercetum roboris* Raus 1969.	120	66.7 ha	11.8° C	691 mm	Loessial clay	Planosol dystric	59 Humid
Sombor	45°46' N 18°56´ I	83 - 86	*Carpino betuli-Quercetum roboris* Anic 1959.	130	27.4 ha	10.6° C	583 mm	Les	Gleysol calcaric	55 Humid
Subotica	46° 07´ N 17° 18´ I	137	*Quercetum roboris* Jov. et Tomic 1979.	60	2.2 ha	10.9° C	555 mm	Les	Arenosol calcaric	51 Humid
Vrsac	45° 07´ N 21° 25´ I	76 - 80	*Carpino–Fraxino-Quercetum roboris* Mis. et Broz 1962.	130	13.6 ha	11.5° C	659 mm	Schists	Gleysol mollic	57 Humid

- Rain factor and classification of climatic areas by Lang; $L = h_{g,n}/t_{g,n}$, $0 < L \leq 20$ desert, arid; $20 < L \leq 40$ semi-desert, arid; $40 < L \leq 60$ steppes and savannas, humid; $60 < L \leq 100$ low forest, humid; $100 < L \leq 160$ high forest, humid; $L > 106$ steppes and tundra, perhumid.

The site Vrsac is in the riparian area of the river Karas in East Serbia, along the border with Romania. The typology of this forest of pedunculate oak, hornbeam, ash and field maple is Ass. *Carpino – Fraxino – Quercetum roboris* Mis. et Broz.

1962. subass. *inundatum*. The determined soil type is gleysol mollic (Table 1, Table 2).

Table 2: Soil properties in the analyzed sites

Location	Soil type	Depth	Texture	pH H_2O	Organic C	Total N	Available P_2O_5	Available K_2O
		(cm)			%	%	mg/100 g	
Ada Ciganlija	Fluvisol calcaric	0 - 5	Loam	7.9	4.32	0.37	11.51	30.55
		5 - 10	Clay loam	8.0	2.01	0.60	13.30	18.81
		10 - 20	Clay loam	8.3	2.12	0.50	7.19	10.63
		20 - 40	Loam	8.4	1.26	0.18	< 1	8.21
		40 - 80	Clay loam	8.3	1.07	0.25	< 1	6.36
Bojcinska suma	Planosol dystric	0 - 5	Clay loam	4.7	3.34	0.34	1.59	20.89
		5 - 10	Clay loam	4.9	2.40	0.27	1.48	17.07
		10 - 20	Clay loam	4.7	1.91	0.25	1.54	12.93
		20 - 40	Clay	5.0	1.52	0.19	1.71	12.49
Sombor	Gleysol calcaric	0 - 5	Loam	7.3	6.45	0.53	2.40	17.72
		5 -10	Loam	7.4	3.35	0.41	1.20	16.43
		10 - 20	Clay loam	7.5	1.08	0.22	1.20	12.12
		20 - 40	Loamy sand	7.8	0.21	0.18	< 1	8.30
		40 - 80	Sandy loam	7.8	0.32	0.11	< 1	7.30
		80 - 100	Loamy sand	8.0	0.14	0.12	< 1	9.20
Subotica	Arenosol calcaric	0 - 5	Loamy sand	7.7	1.36	0.24	2.40	3.80
		5 -10	Loamy sand	7.9	0.67	0.24	1.40	1.60
		10 - 20	Loamy sand	8.1	0.37	0.15	< 1	2.40
		20 - 40	Loamy sand	8.1	0.06	0.02	< 1	6.30
		40 - 80	Loamy sand	8.1	0.06	0.02	< 1	2.80
Vrsac	Gleysol mollic	0 -5	Clay	7.4	2.18	0.50	2.70	9.07
		5 -10	Clay	7.2	1.14	0.25	1.88	4.29
		10 - 20	Clay	7.1	1.19	0.36	2.02	4.19
		20 - 40	Clay	7.2	0.96	0.22	4.33	4.67
		40 - 80	Clay	7.3	0.85	0.18	3.48	5.02

Based on the data on the mean annual temperature and quantity of precipitation for each analysed locality, the rain factor was calculated and the climate regions by using the method Lang was classified (UNKASEVIC *et al.* 2002).

Foliar and soil analysis

The leaves were sampled on all sites during the same year, in the second half of August and first half of September, when there is a lowest oscillation in the content of nutrients (SELETKOVIC 2003). Four branches were cut from each tree from all four sides, from the lower third of the crown at the height of 3 - 5m. After the leaves were removed from short shoots in the first growth phase, air dried and ground, the powder was used for foliar analysis (DAVIS *et al.* 1995; SABATE *et al.*

1995; BONNEAU 1996; OLIVEIRA *et al.* 1996; KREMER *et al.* 2002; PONTON *et al.* 2004).

The content of nutrients in pedunculate oak foliage was examined by leaf ash analysis, after dry burning 550° C. Ash analysis included the determination of P content by colorimetric method, K and Na contents by flame photometry and Ca and Mg content by titrimetric method with titriplex III as titration agent. Nitrogen content in plant material was determined by the distillation of ammonium from the samples prepared by Kjeldahl method (DZAMIC *et al*. 1996).

Soil types were determined in soil profiles opened at each study site, and soil samples for laboratory analyses were taken at fixed depths. The soil sample analyses included:

- The textural fraction of the coarse sand was determined by the wet sifting by the sift, the openings of which are 0.2 mm. The fractions silt and clay were determined by the use of pipette, after the certain period of sedimentation. $Na_4P_2O_7$ 0.1mol/l was used as a peptizing agent. Carbonates, gypsum and organic matter were not removed from the samples. The textural class was determined by the Ferre triangle.
- Active acidity of soil solution was determined electrometrically.
- Content of organic matter was determined by Turin method, by wet combustion in the mixture of K_2CrO_7 and H_2SO_4.
- Total N content was determined by Kjeldahl – method.
- Available forms of P_2O_5 and K_2O were determined by AL – method.

The extraction was conducted in 1.7 percentage solution of acetic acid, which contains 0.1 mol/l of lactic acid, and 0,1 mol/l ammonium acetate. From the extract obtained in this way P was determined colorimetrically, whereas K was determined flame-photometrically.

The data were statistically processed using software STATGRAPHICS Plus (Version 5.0: *Statistical Graphics Corporation*, USA); analyses of variance (ANOVA), LSD test (at α =0.05 significance level).

RESULTS

Foliar and soil analysis

Based on the results of foliar analysis for all sites and analyzed trees indicates variability in the content of macroelements both within and between localities. Taking into account all the analyzed sites the highest variability, was shown by Na - 38.95 %, followed by Mg - 34.08 %, Ca - 30.43 %, something less K - 24.20 % and P - 22.95 %, and the least variable were N - 15.52 % (Table 3). The differences among the sites were statistically highly significant for all analyzed macroelements, with the exception of K and Na (Table 4). The results of the ANOVA revealed no statistically significant difference between sites for the content of macroelements Mg, Ca, P and N (all P <0.0001). Statistically significant intra-individual variation between trees within the population was obtained only for Ca (P <0.0224) (Table 4).

Table 3a: Macroelements content in the leaf of the trees of the analyzed localities

Study sites	min	max	$\overline{X} \pm Sx$	S ± Ss	V ± Sv
Mg (%)					
Ada Ciganlija	0.50	1.26	$0.91^{c} \pm 0.04$	0.2001 ± 0.0263	22.04 ± 2.89
Bojcinska suma	0.29	1.08	$0.71^{b} \pm 0.03$	0.1786 ± 0.0231	25.24 ± 3.26
Sombor	0.19	1.21	$0.70^{b} \pm 0.04$	0.1955 ± 0.0257	28.13 ± 3.69
Subotica	0.02	0.98	$0.67^{b} \pm 0.04$	0.2130 ± 0.0271	31.79 ± 4.04
Vrsac	0.14	0.98	$0.51^{a} \pm 0.04$	0.2263 ± 0.0292	44.55 ± 5.75
All sites	0.02	1.26	0.6961 ± 0.0194	0.2373 ± 0.0137	34.0828 ± 1.9678
Ca (%)					
Ada Ciganlija	0.89	2.65	$1.62^{c} \pm 0.08$	0.4548 ± 0.0597	28.02 ± 3.68
Bojcinska suma	0.77	2.58	$1.40^{b} \pm 0.07$	0.3991 ± 0.0515	28.47 ± 3.67
Sombor	0.72	3.28	$1.61^{c} \pm 0.10$	0.5544 ± 0.0728	34.38 ± 4.51
Subotica	0.59	1.83	$1.18^{a} \pm 0.04$	0.2470 ± 0.0314	20.93 ± 2.66
Vrsac	0.93	1.69	$1.24^{ab} \pm 0.04$	0.2059 ± 0.0266	16.55 ± 2.14
All sites	0.59	3.28	1.4094 ± 0.0350	0.4288 ± 0.0248	30.4266 ± 1.7567
K (%)					
Ada Ciganlija	0.61	1.80	$1.27^{a} \pm 0.06$	0.3114 ± 0.0409	24.57 ± 3.23
Bojcinska suma	0.72	1.53	$1.22^{a} \pm 0.03$	0.1911 ± 0.0247	15.68 ± 2.02
Sombor	0.65	1.72	$1.18^{a} \pm 0.06$	0.2990 ± 0.0393	25.33 ± 3.33
Subotica	0.52	1.99	$1.11^{a} \pm 0.06$	0.3553 ± 0.0451	32.04 ± 4.07
Vrsac	0.73	1.67	$1.22^{a} \pm 0.05$	0.2588 ± 0.0334	21.26 ± 2.74
All sites	0.52	1.99	1.1976 ± 0.0237	0.2898 ± 0.0167	24.1999 ± 1.3972

Table 3(continuited): Macroelements content in the leaf of the trees of the analyzed localities

Na (%)

Study sites	min	max	$\bar{X} \pm Sx$	S ± Ss	V ± Sv
Ada Ciganlija	0.015	0.036	0.0222[a] ± 0.001	0.0060 ± 0.0008	26.96 ± 3.54
Bojcinska suma	0.009	0.050	0.0216[a] ± 0.002	0.0105 ± 0.0014	48.81 ± 6.30
Sombor	0.015	0.057	0.0248[a] ± 0.002	0.0108 ± 0.0014	43.55 ± 5.72
Subotica	0.013	0.060	0.0251[a] ± 0.002	0.0112 ± 0.0014	44.61 ± 5.66
Vrsac	0.016	0.032	0.0226[a] ± 0.001	0.0044 ± 0.0006	19.44 ± 2.51
All sites	0.009	0.060	0.0233 ± 0.0007	0.0091 ± 0.0005	38.9535 ± 2.2490

P (%)

Study sites	min	max	$\bar{X} \pm Sx$	S ± Ss	V ± Sv
Ada Ciganlija	0.106	0.254	0.147[a] ± 0.006	0.0298 ± 0.0039	20.22 ± 2.65
Bojcinska suma	0.160	0.273	0.208[c] ± 0.005	0.0272 ± 0.0035	13.10 ± 1.69
Sombor	0.117	0.196	0.163[b] ± 0.004	0.0199 ± 0.0026	12.22 ± 1.60
Subotica	0.112	0.190	0.154[ab] ± 0.004	0.0215 ± 0.0027	13.92 ± 1.77
Vrsac	0.202	0.292	0.233[d] ± 0.004	0.0245 ± 0.0032	10.50 ± 1.36
All sites	0.106	0.292	0.1811 ± 0.0034	0.0416 ± 0.0024	22.9450 ± 1.3247

N (%)

Study sites	min	max	$\bar{X} \pm Sx$	S ± Ss	V ± Sv
Ada Ciganlija	2.13	3.23	2.61[c] ± 0.06	0.3067 ± 0.0403	11.75 ± 1.54
Bojcinska suma	0.91	2.96	2.20[a] ± 0.10	0.5368 ± 0.0693	24.44 ± 3.15
Sombor	1.67	2.81	2.27[ab] ± 0.05	0.2841 ± 0.0373	12.53 ± 1.64
Subotica	1.83	3.14	2.52[c] ± 0.04	0.2386 ± 0.0303	9.46 ± 1.20
Vrsac	1.76	2.98	2.45[bc] ± 0.05	0.2769 ± 0.0357	11.31 ± 1.46
All sites	0.91	3.23	2.4087 ± 0.0305	0.3739 ± 0.0216	15.5215 ± 0.8961

The values of different letters are significantly different at the 0.05 probability level according to the results of the LSD test.

Table 4: Analysis of variance for the analyzed parameters of foliar analysis

Nutrients	Analysis of variance					
	Source	Sum of Squares	Df	Mean Square	F - Ratio	P - Value
Mg	study sites	2.01217	4	0.50305	11.12	0.0000
	trees	1.06978	36	0.02972	0.66	0.9248
	RESIDUAL	4.93145	109	0.04525		
	TOTAL	8.38769	149			
Ca	study sites	5.10903	4	1.27726	9.66	0.0000
	trees	7.96517	36	0.22126	0.67	0.0224
	RESIDUAL	14.4175	109	0.13228		
	TOTAL	27.399	149			
K	study sites	0.37881	4	0.09470	0.99	0.4175
	trees	1.64422	36	0.04567	0.48	0.9937
	RESIDUAL	10.452	109	0.09589		
	TOTAL	12.516	149			
Na	study sites	0.00028	4	0.00007	0.77	0.5498
	trees	0.00236	36	0.00006	0.74	0.8470
	RESIDUAL	0.00962	109	0.00009		
	TOTAL	0.01228	149			
P	study sites	0.16527	4	0.04132	64.19	0.0000
	trees	0.01890	36	0.00052	0.82	0.7546
	RESIDUAL	0.07016	109	0.00064		
	TOTAL	0.25736	149			
N	study sites	3.25259	4	0.81315	7.44	0.0000
	trees	5.35759	36	0.14882	1.36	0.1137
	RESIDUAL	11.9061	109	0.10923		
	TOTAL	20.8266	149			

Statistically significant effect at the 95.0% confidence level

Based on the average percentages of the analyzed macroelements, their sequence was the same at all sites: N>Ca>K>Mg>P>Na. As for the concentration of N, there were statistically highly significant differences among the sites; it was the highest (2.61 %) at the locality Ada Ciganlija and the lowest (2.20 %) at locality Bojcinska suma (Fig. 1).

As for the concentration of P, there were also statistically highly significant differences among the sites; locality Vrsac exhibited the highest (0.233 %) values of P and locality Ada Ciganlija had the lowest (0.147 %) values (Fig.2). At all other sites, the amounts of readily available P in the deeper layers were below the detection limit by AL - method.

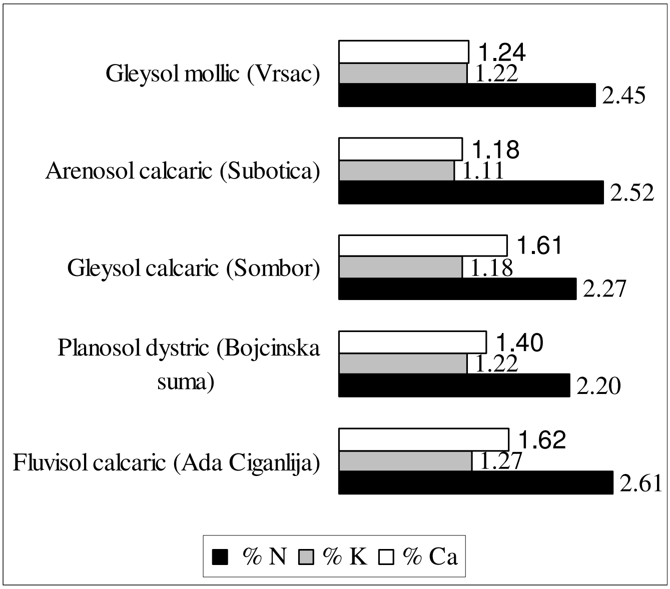

Figure 1**:** Macroelements (N, K and Ca) content in the leaf for the analyzed localities

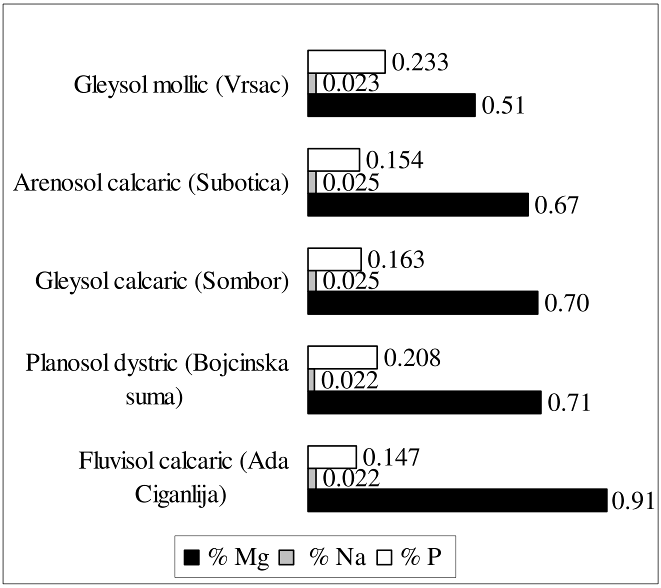

Figure 2: Macroelements (Mg, Na and P) content in the leaf for the analyzed localities

The contents of Ca and Mg also showed statistically highly significant differences. The highest values of Ca were measured at locality Ada Ciganlija (1.62 %), and the lowest (1.18 %) at locality Subotica (Fig. 1,2). Locality Ada Ciganlija was also distinguished by the highest percentage of Mg (0.9 %), and locality Vrsac exhibited the lowest values (0.51 %). The high concentration of earth alkaline elements in pedunculate oak foliage at locality Ada Ciganlija was the consequence of the higher content of these elements in the soil. Of all the study sites, the soil solution pH was the highest at locality Ada Ciganlija, because the river Sava sediment is rich in carbonates (MILJKOVIC 1972). Based on the soil pH, high quantities of earth alkaline elements in pedunculate oak leaves could also be expected at locality Subotica on arenosol, however this site showed the lowest Ca percentage in the leaves. The aeolian sands of Suboticko – Horgoska Pescara are also rich in the carbonates of earth alkaline elements (Letic et al. 2001).

As regards the percentages of K and Na, regardless of the observed individual variability of 1.11 % - 1.27 % for K and from 0.0216 % - 0.0251 % for Na, there was no statistically significant differences among the sites (Table 4, Fig. 1,2).

The results of the foliar analysis point to the evident differences between the sites. On the site Ada Ciganlija a higher content of Mg, Ca, K and N was registered, whereas the content of P was lower than at other localities. The site Bojcinska suma has the lowest content of Na and N. The site Subotica is distinguished by the content of Na, and to the less extent by Ca and K. On the site Sombor the extreme values of the content of neither element was not registered. The site Vrsac has the highest content of P, and the lowest quantity of Mg (Table 3, Fig. 1,2).

The types of soils registered on five analysed sites are: fluvisol calcaric (Ada Ciganlija), planosol dystrict (Bojcinska suma), gleysol calcaric (Sombor), and gleysol mollic (Vrsac). In regard of its physical and chemical characteristics the studied types of soil differ to a great extent. By the textural class, they belong to clays (gleysol mollic) and loamy sand (arenosol calcaric). By the reaction of the soil solution, they range from acidified (planosol dystric), to alkaline (fluvisol calcaric and arenosol calcaric). The content of the organic C, as well as total N, in all the studied profiles is the highest in the surface (0-5 cm) layer, and it decreases with the solum depth, whereas fluvisol calcaric is the exception. The content of P form available to plants in all profiles is the highest in the surface layer, and it decreases with the depth. The exception to the rule is site Vrsac, on which the quantity of the available P forms increases with the depth. On the site Ada Ciganlija the middle P availability is registered in the surface layers, by the limit values for AL-method, whereas in the deeper layers it is below the detection level. In all other profiles P content is within the limits of poor availability. It can be concluded that on the sites Subotica (arenolsol calcaric) and Vrsac (gleysol mollic) the content of the K, which is available to plants, is within the limits of poor availability, by the limit values for AL-method. On the site Bojcinska suma it is within the limits of middle availability. On site Sombor the middle K availability is registered only in the surface part of solum (20 cm), while in the deeper parts the weak availability is registered. There is a similar situation on the site Ada Ciganlija.

DISCUSSION

Site and climatic conditions have a dominant effect on the nutrient uptake (KUZNOVA *et al*. 2007). The differences between the content of macroelements in pedunculate oak leaves, which are of great statistical importance, between the analysed localities are predominantly the results of the different site conditions in this research as well.

In regard of the climate indicators, the site Subotica is singled out as the most arid area. As a result, the conditions for adoption of the nutrients from the soil are less favourable on this site, in comparison with the conditions of other sites. Along with the climate conditions, the nutrition is further hindered by the type of soil registered on this site (arenosol calcaric), which is characterized by the low textural content, as well as by the low water retaining capacity. It can be the cause of the constantly low Ca and Mg content in leaves, in spite of the fact that the sand of Suboticko-Horgos sands are rich in these elements (LETIC *et al*. 2001).

The most humid locality is Bojcinska suma. The type of soil on this site is planosol dystrict, with the well-expressed stagnic processes, which is also reflected in the less favourable conditions for the nutrition of plants. The creation of anaerobic and anoxidative conditions, which is the characteristic of this type of soil, can decelerated the N mineralization and its transformation in the forms which are available to plants (TESIC and TODOROVIC 1988). Microbial activity in a soil may be adversely affected by either very high or low soil water content (ALBRECHT and LONG 2008). The reaction of the soil solution is acidified. N mineralization ends at the stage of ammonification. The ammonium N form is considerably less mobile and migrates in the deeper solum layers to a less extent. If the fact that it is the soil of the heavier textural content is taken into account, the absorption capacity is high and NH_4^+ is mainly absorbed in the absorptive complex (SAVIC and JEKIC 1975). It only enables the nutrition of the plants that take root in shallow soil layers. The migration of N, which is available to plants out of the water-resistant horizon, is not present on this site, which is the reason for the poor nutrition of pedunculate oak by N on this site.

On the site Ada Ciganlija the greatest amounts of all macroelements in pedunculate oak leaves were registered, except for P. As a result, the site conditions for the adoption of nutrients from the soil are most favourable. The type of soil - fluvisol calcaric, registered on this site, is characterized by the high pH value of soil solution, light textural content, as well as a good aeration of the surface layers.

Nitrogen mineralization slightly increased with increasing soil moisture under similar conditions of soil carbon concentration (ALBRECHT and LONG 2008). The moisture soil conditions on this site are favourable, since the flooding was stopped by the construction of the embankment, which implies that the further creation of anaerobic conditions in the profiles is no longer possible. It enables the fast organic N forms mineralization, and its transformation into the mineral forms, which are available to plants. Fluvisol calcaric also provides the sufficient quantities of the alkaline earth elements, as well as of K, necessary for the nutrition of pedunculate oak. In spite of the fact that there is a high content of P forms available to the plants in the surface fluvisol layers, the lower content of this element in comparison with the other sites can be explained by its low content in the deeper layers of soil (below the detection limit). The quantities of the nutrients in pedunculate oak leaves on the sites Sombor and Vrsac are greater than on the localities Bojcinska suma and Subotica, on which the conditions for adoption of nutrients are the most unfavorable, and smaller than on the Ada Ciganlija, where the conditions for nutrition are the most favourable. The type of soil gleysol calcaric, registered on the site Sombor, creates the better conditions for nutrition by Ca and Mg in comparison with gleysol mollic registered on the site Vrsac.

The higher content of P at Vrsac, on gleysol mollic, was the consequence of higher extractable amounts of P forms available in the soil, and particularly in the deeper layers of the solum wherefrom pedunculate oak absorbs water and nutrients. On the other sites studied in this paper, the available P forms were registered only in the surface layers, up to 20 cm deep, which do not have great influence on the nutrition of pedunculate oak, since this element is characterized by the poor solubility and migrates at a slow rate through the soil solum.

The stand conditions, mainly canopy and light penetration in the soil surface are, along with spatial variability of soil characteristics, the significant cause of the variability of the content of macroelements within a population. .

The observed high individual variability in nutrient concentrations in pedunculate oak foliage at the analyzed sites suggest the potential effect of microsite conditions and the need of a more detailed analysis, which was also pointed out by SAUVESTY *et al*. (1993).

At some sites, there were individual trees with very high or very low contents of some macroelement in leaves. It mainly refers to K content. Having in mind all the analyzed trees and localities, K content at locality Subotica had the greatest and smallest values (0.52 %, 1.99 %, respectively). The results of our researches show that this element is in the middle of the observed sequence of the analyzed elements, regarding the degree of variability.

Based on the calculation of the coefficient of variation, different authors report greatly different even contradictory values of variability in individual elements. The results obtained by NIKOLIC and ORLOVIC (2001) are similar to ours; the highest individual variability in pedunculate oak foliage was shown by Na, Ca, K and P and the lowest by N. The highest variability of N and P in pedunculate oak was found by GALLARDO and COVELO (2005). CANADELL and VILA (2004) analysed the nutrient content in *Quercus ilex* leaves and in three types of soil and found that N and K had the lowest variation. The values of elemental concentrations differ depending on the authors. The identical sequence of average values of nutrient percentages (N>Ca>K>Mg>P>Na) was also reported by NIKOLIC *et al*. (2001) and NIKOLIC *et al*. (2006) in foliar analysis of pedunculate oak clones in the seed orchard Banov Brod in Vojvodina (Serbia). The above authors claim that the differences between the clones are genetically controlled because the individuals developed under the same environmental conditions. A similar sequence of macroelements was also reported by CANADELL and VILA (1992) for *Q. ilex*. In this context, it would be best to compare the results obtained in the identical site conditions and experimental conditions in general.

The phenological cycle, i.e., the leaf development stage is also significant for the level of nutrient accumulation (ROBERT *et al*. 1996; SANTA REGINA *et al*. 1997; ORGEAS *et al*. 2002; SELETKOVIC 2003). OLIVEIRA *et al.* (1996) confirmed that there was seasonal variability in the nutrient content in cork oak in Portugal which was observed for the majority of nutrients except for Mg, which had the highest individual variability. Also there are differences in nutrient content depending on the leaf stage, although they can be substantially lower in current-year leaves than in older leaves (CANADELL and VILA 2004). Seasonal variability in nutrients, as well as the variability depending on the leaf stage, was not the subject of our research. Their effect was reduced to the minimum by simultaneous sampling of the leaves in the first growth phase, as it was noted in the Materials and methods.

CONCLUSION

In regard of the content of the analyzed macroelements of pedunculate oak, trees on the site Ada Ciganlija are the richest, whereas the trees on the site Subotica are the poorest. Also on the site Ada Ciganlija the conditions of organic matter mineralization and nutrient migration through the soil profile are the most favourable. This is enabled by the favourable textural composition of the soil, good aeration of the surface soil layers and favourable pH of the soil solution. At locality Subotica, on arenosol, the delay in the organic matter mineralization and release of plant nutrients is caused by fast drying of surface layers.

The results of the foliar and pedologic analysis serve as a proof of the significant differences among the analyzed localities. The site Ada Ciganlija had the most favourable conditions for the development of pedunculate oak, whereas on the site Subotica the conditions for development of pedunculate oak are extremely unfavorable.

Also as the result of analysis we can conclude that intra-individual variation between trees within each locality is not statistically significant for the analyzed macroelements, except for the concentration of Ca. Just for this macroelement content we can say that there is genetic variability for the concentration of Ca in leaves differed between trees within the site.

The absorption of nutrients depends on the amount of rainfall, bedrock, physical and chemical properties of the soil, micro flora and, certainly, the plant condition. Based on the higher content macroelements in some individual trees, it is necessary to research the micro site conditions, which would contribute to the elucidation of the individual - environment effect.

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VARIJABILNOST MAKROELEMENATA ISHRANE U LISTU LUŽNJAKA (*Quercus robur* L.) NA PODRUČJU SRBIJE

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I z v o d

Lužnjak (*Quercus robur* L.) je na području Srbije danas mnogo manje raprostranjen nego nekada što je posledica prvenstveno preterane eksploatacije i otežanog obnavljanja usled promene režima podzemnih voda. Istraživanja u ovom radu su imala za cilj analizu varijabilnosti sadržaja makroelemenata u lišću lužnjaka (*Quercus robur* L.) i osobina zemljišta u populacijama lužnjaka na različitim staništima, na osnovu čega bi se izdvojila staništa koja imaju najbolje uslove za ishranu lužnjaka. Analizirane populacije su prirodnog ili veštačkog porekla, nastale u procesu restitucije. Nalaze se u zoni kontinentalne do umereno kontinentalne klime, na pet različitih lokaliteta i pet različitih tipova zemljišta. Folijarnom analizom 150 individua-stabala lužnjaka na 5 lokaliteta na području Srbije i analizom zemljišta sa istih lokaliteta ustanovljena individualna varijabilnost makroelemenata između stabala nije bila statistički opravdana dok su razlike između lokaliteta bile visoko značajne. Koncentracija elemenata, na svim lokalitetima, bila je u opadajućem nizu: N>Ca>K>Mg>P>Na. Najveću individualnu varijabilnost imao je Na, zatim Mg, Ca i K a najmanje varijabilni bili su P i N. Dobijeni rezultati upućuju na zaključak da je varijabilnost sadržaja makroelemenata u listu prvenstveno posledica sredinskog uticaja.

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