Pak. J. Bot., 41(6): 3169-3178, 2009.

LEAF NUTRITIONAL STATUS AND MACRONUTRIENT DYNAMICS IN EUROPEAN HAZELNUT (*CORYLUS AVELLANA* L.) UNDER WESTERN SERBIAN CONDITIONS

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Abstract

Research was conducted on the leaf content of N, P, K, Ca and Mg in the cvs. Tonda Gentile Romana, Nochione and Istarski Duguljasti during the growing season in 2005-2007 under the environmental conditions of Gornji Milanovac (Western Serbia). Highest seasonal changes were observed in the contents of Mg (CV=18.19%) and N (CV=12.95%) and the lowest ones in P content (CV=4.00%). Highest leaf contents of N (1.83±0.07%), P (0.43±0.09%) and K (1.77±0.04%) during the season were produced by cv. Nochione and those of Ca (1.27±0.07%) and Mg (0.44±0.42%) by cvs. Tonda Gentile Romana and Istarski Duguljasti, respectively. The study showed highest effect on the hazelnut leaf content of the above nutrients with the exception of Ca. The effects of the year and the cultivar × year interactions being less pronounced.

Introduction

Fruit nutrition has been studied since the turn of the century and its history has been reviewed (Faust, 1979). Essential elements (N, P, K, Ca and Mg) used by plants in relatively large amounts for plant growth are called macronutrients and all of these five nutrients are important constituents in soil that promote plant growth (Munshower, 1994). Plant analysis is primarily used as a diagnostic tool, except for fruit and nut growers, many of whom perform tests yearly in order to formulate fertilizer recommendations for next years crop (Jones, 1993). There is a significant gap in research worldwide on the fertilizer requirement of hazelnut and most of the nutrient research has been focused on leaf rather than soil analyses (Tous *et al*., 1994). Successful hazelnut growing necessitates, among other things, the knowledge of major biological, i.e., biochemical and physiological characteristics and processes taking place in its organs. The dynamics displayed during the vegetation cycle and the nutrient content of the hazelnut leaf (deficiency, optimum, excess) are directly correlated with the soil nutrient content (Kowalenko, 1984, 1996; Horuz & Korkmaz, 2008), soil pH (Hart, 1986; Adiloglu & Adiloglu, 2005), the water content of soil (Jones, 1993), cultivar and overall pedoclimatic conditions (Canali *et al*., 2005). Many authors studied the optimum macronutrient content in hazelnut leaves, but often reported differing data and wide ranges of values of certain elements as dependent on the cultivar i.e., the genotype used and the environmental conditions. The optimum contents of nitrogen, phosphorus, potassium, calcium and magnesium range from 1.20-3.54%, 0.10-0.60%, 0.36-3.00%, 0.60-2.50% and 0.18-1.00%, respectively (Painter, 1963; Childers, 1973; Molne, 1976; Shear & Faust, 1980; Chaplin, 1981; Romisondo *et al*., 1983; Lopez-Acevedo, 1983; Kowalenko, 1984, 1996; Miletic *et al*., 2001; Horuz & Korkmaz, 2008).

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The objectives of the present study were to study the dynamics of the macronutrient content of leaves during the vegetation cycle of hazelnut and to determine the provisional standards for the interpretation of foliar analysis. The results obtained were used to describe general trends and variability in the leaf concentrations of nutrients during the vegetative cycle of hazelnut.

Materials and Methods

The trial was conducted in the hazelnut orchard at the village of Vracevsnica, 18 km northeast of the town of Gornji Milanovac (44°02'; 20°29'), Western Serbia. The hazelnut cultivars Tonda Gentille Romana, Nochione and Istarski Duguljasti were used in the experiment. The bushes were planted in a randomized block design with four replications at a 5 × 4 m spacing (500 bushes ha^{-1}). The trial was conducted at the full bearing stage (12-14 years upon planting). The orchard soil was eroded vertisol with a pH 5.2 in 0.1M KCl. The results of the soil chemical analysis showed that the soil contained 0.98-2.92% humus and 0.16% N. The contents of P_2O_5 and K_2O ranged from 44.0-52.0 mg kg^{-1} and from 250.0-309.0 mg kg^{-1}, respectively. The orchard was fertilized with 500 kg of NPK (15:15:15) mineral fertilizer in autumn and with 300 kg ha^{-1} of CAN (Calcium Ammonium Nitrate, containing 27% of total N) prior to the onset of the growing season. All major cultural practices were applied.

Leaf sampling was conducted every thirty days from 15 May to 15 September. The leaf samples were washed with distilled water, dried and mill-ground. The ground samples were digested with concentrated nitric (HNO_3) and perchloric acids ($HClO_4$) at the ratio of 4:1 and analyzed for P colorimetrically and for K, Ca and Mg by atomic absorption spectrophotometry (AAS) using the "Pye Unicam SP 191" atomic absorber. Total nitrogen was measured by a Kjeldahl method employing sulfuric acid (H_2SO_4) and a metal catalyst.

The experimental data were subjected to the analysis of variance. An LSD test at $p<0.05$ and $p<0.01$ was used for mean separation. The data were analyzed by the ANOVA statistical programme, Statistica 6.0 (StatSoft®) software for Windows (StatSoft Inc., 2001). The theoretical dynamics of the leaf macronutrient content of hazelnut during the growing season is presented by the square function $Y = a \pm bx \pm cx^2$.

Results and Discussion

Content of nitrogen: The cultivar and the cultivar × year interaction had a significant ($p<0.01$) effect on the nitrogen content of hazelnut leaves during the vegetative cycle, whereas the effect of the year was not significant (Table 1). The N content ranged from 1.36±0.09 (Istarski Duguljasti) to 1.83±0.07% (Nochione) among the cultivars, and from 1.56±0.08 (2006) to 1.67±0.07% (2007) between the years. The highest N content was recorded in the leaf of cv. Nochione in 2007 (1.93±0.06%). The dynamics of leaf N content (Fig. 1) showed different intensity in the cultivars studied (CV=12.95%). The highest intensity was found in cv. Nochione which had a higher N content during the three-year growing cycle as compared to cvs. Tonda Gentile Romana and Istarski Duguljasti. The highest content of N in cvs. Tonda Gentile Romana and Istarski Duguljasti was recorded during mid-growing season and that in cv. Nochione at the beginning and end of the vegetation cycle.

Table 1. The effect of cultivar, year and cultivar × year interaction on the leaf macronutrient content in hazelnut grown under the environmental conditions of Western Serbia (mean ± SE).

Parameter		Macronutrient content (% of dry matter)				
		Nitrogen (N)	Phosphorus (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)
Cultivar (A)						
Tonda Gentile Romana		1.62 ± 0.08 b	0.41 ± 0.10 b	1.52 ± 0.05 c	1.27 ± 0.07 a	0.30 ± 0.61 c
Nochione		1.83 ± 0.07 a	0.43 ± 0.09 a	1.77 ± 0.04 a	1.12 ± 0.08 a	0.34 ± 0.53 b
Istarski Duguljasti		1.36 ± 0.09 c	0.40 ± 0.10 c	1.65 ± 0.04 b	1.25 ± 0.07 a	0.44 ± 0.42 a
Year (B)						
2005		1.58 ± 0.08 a	0.41 ± 0.10 b	1.70 ± 0.04 a	1.25 ± 0.07 a	0.37 ± 0.49 a
2006		1.56 ± 0.08 a	0.43 ± 0.09 a	1.60 ± 0.04 a	1.20 ± 0.07 a	0.35 ± 0.52 b
2007		1.67 ± 0.07 a	0.40 ± 0.10 c	1.64 ± 0.05 a	1.20 ± 0.07 a	0.36 ± 0.50 ab
A × B						
	2005	1.53 ± 0.08 c	0.41 ± 0.10 a	1.63 ± 0.05 a	1.23 ± 0.07 a	0.31 ± 0.59 c
Tonda Gentile Romana	2006	1.54 ± 0.08 c	0.43 ± 0.09 a	1.51 ± 0.05 a	1.18 ± 0.07 a	0.27 ± 0.67 d
	2007	1.78 ± 0.07 b	0.40 ± 0.10 a	1.41 ± 0.05 a	1.41 ± 0.06 a	0.32 ± 0.57 c
	2005	1.80 ± 0.07 b	0.43 ± 0.09 a	1.75 ± 0.04 a	1.17 ± 0.07 a	0.33 ± 0.55 c
Nochione	2006	1.75 ± 0.07 b	0.44 ± 0.09 a	1.76 ± 0.04 a	1.20 ± 0.07 a	0.31 ± 0.59 c
	2007	1.93 ± 0.06 a	0.42 ± 0.09 a	1.80 ± 0.04 a	1.00 ± 0.09 a	0.38 ± 0.48 b
	2005	1.40 ± 0.09 d	0.40 ± 0.10 a	1.72 ± 0.04 a	1.34 ± 0.07 a	0.47 ± 0.39 a
Istarski Duguljasti	2006	1.39 ± 0.09 d	0.41 ± 0.10 a	1.53 ± 0.05 a	1.23 ± 0.07 a	0.47 ± 0.39 a
	2007	1.30 ± 0.08 d	0.39 ± 0.10 a	1.71 ± 0.04 a	1.19 ± 0.07 a	0.39 ± 0.47 b
ANOVA						
Cultivar (A)		**	**	**	ns	**
Year (B)		ns	**	ns	ns	**
A × B		**	ns	ns	ns	**
CV (%)		12.95	4.00	7.69	8.83	18.19

A and B represent 'Cultivar' and 'Year' treatment, respectively
The letter (s) and asterisks in vertical columns indicate a significant difference between means at $p<0.01$ level by LSD test
ns = non-significant differences

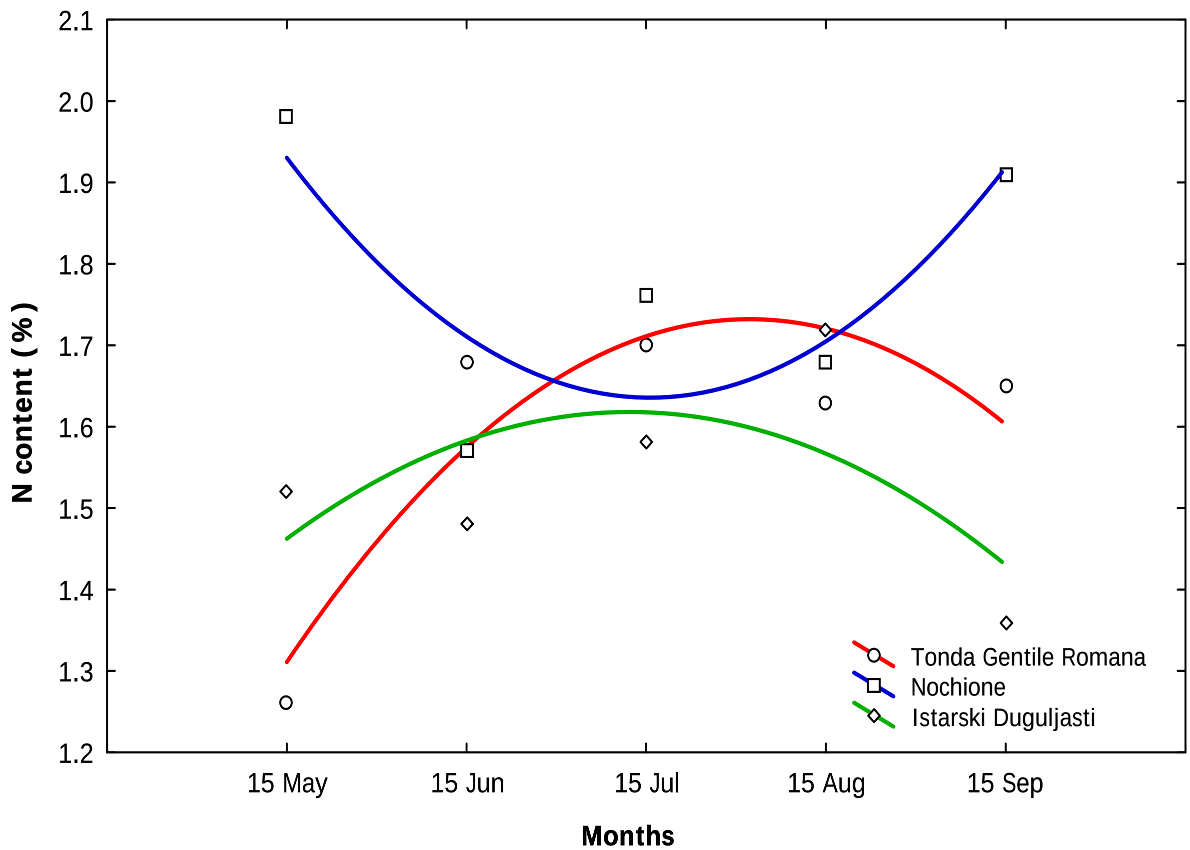

Fig. 1. The highest N content in the cvs. Tonda Gentile Romana and Istarski Duguljasti was recorded during the mid-growing seasons and that in the cv. Nochione at the beginning and at the end of the vegetative cycle.

Nitrogen is an important element for plant nutrition (Romisondo *et al*., 1983). Nitrogen is important for growth due to the fact that it is a major constituent element of all amino acids, which are the building blocks of all proteins, including the enzymes, which control virtually all biological processes (Brady & Weil, 1999). Inconsistencies are observed in the scientific data on the highest leaf N content during the vegetation cycle. The leaf nitrogen concentration was highest in spring, this decreasing during the growing season (Bignami *et al*., 2005). According to Fregoni & Zioni (1972), the hazelnut wood was moderately supplied with nitrogen, its levels recorded in August. The differences in N content reported in this study were due to a highly significant interactive effect of the cultivar and the year (Canali *et al*., 2005). However, a comparison of the results of the present study with those reported by Painter (1963), Childers (1973), Shear & Faust (1980), Romisondo *et al*., (1983), Kowalenko (1996), Miletic *et al*., (2001) and Horuz & Korkmaz (2008) suggested that the leaf of the studied hazelnut cultivars had the lowest optimum level of nitrogen supply (Table 1).

The soil of the hazelnut orchard used in this research was acid eroded vertisol that had low humus very low total nitrogen supplies. Therefore, the rate of 300 kg ha^{-1} of nitrogen fertilizers for the spring fertilization of hazelnut bushes was insufficient to produce an optimum level of N in the leaf, as the nutrient content of the hazelnut leaf is directly correlated with the soil nutrient content (Kowalenko, 1984, 1996; Horuz & Korkmaz, 2008), soil pH (Hart, 1986; Adiloglu & Adiloglu, 2005), cultivar and overall pedoclimatic conditions (Canali *et al*., 2005).

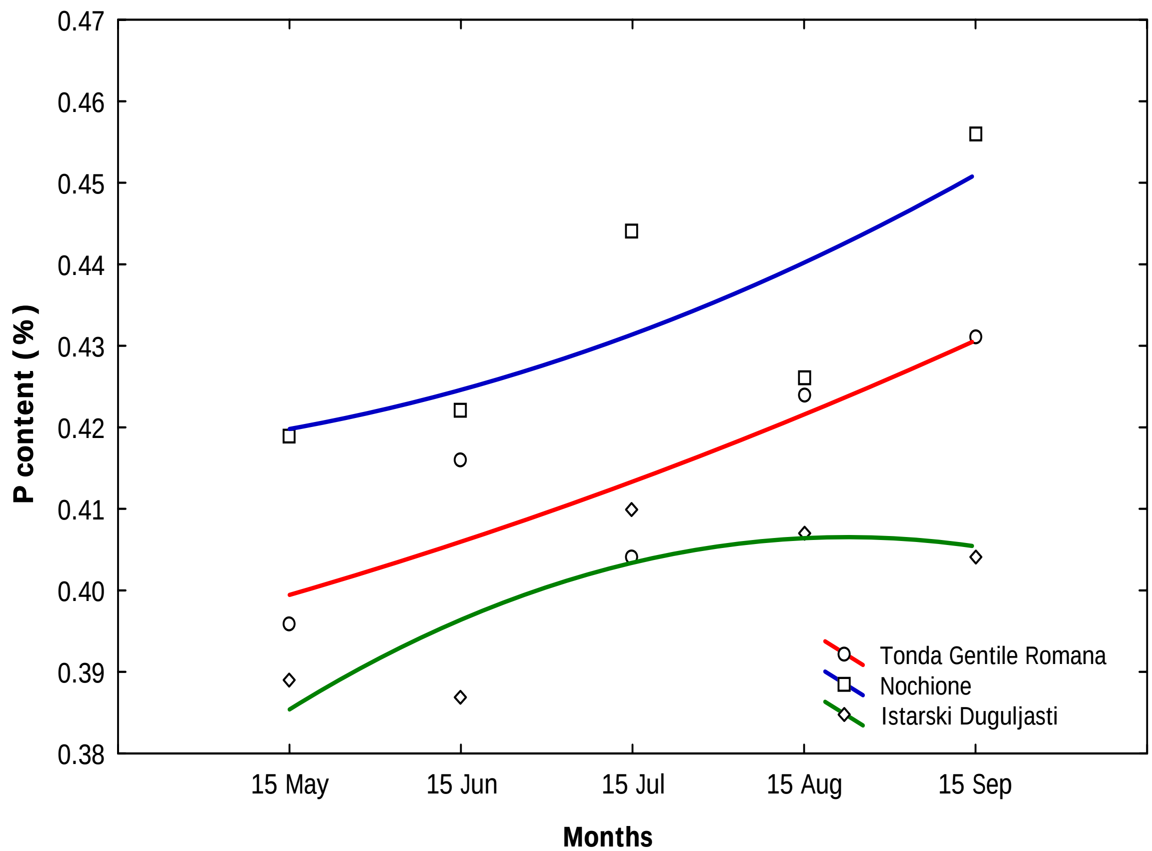

Fig. 2. The accumulation of P in the leaf showed a rising tendency, reaching its maximum at the end of the vegetative cycle, particularly in the leaf of cv. Nochione, followed by cv. Tonda Gentile Romana and Istarski Duguljasti.

Content of phosphorus: The cultivar and the year had a significant (p<0.01) effect on the phosphorus content of hazelnut leaves (Table 1). The cultivar×year interactions did not produce any significant effect on P content. Phosphorus content varied from 0.40±0.10 to 0.43±0.09% among the cultivars, the highest (0.43±0.09%) being obtained in the cv. Nochione, and from 0.40±0.10 (2007) to 0.43±0.09% (2006) between the years. The highest phosphorus content in the our study was recorded in the leaf of cv. Nochione in 2006 (0.44±0.09%), the range of values being rather modest (CV=4.00%). Over the three-year period, the leaf P content in the cultivars during the vegetation cycle showed a rising tendency, the highest content being recorded at the end of the cycle (Fig. 2). The P dynamics was most intensive in cv. Nochione, followed by the cvs. Tonda Gentile Romana and Istarski Duguljasti.

Phosphorous is commonly available in soil as inorganic phosphate ions (HPO_4^{2-} and $H_2PO_4^{2-}$) and sometimes as soluble organic phosphorous (Munshower, 1994). Phosphorus is essential for fertilization and fruit set although hazelnut shows minimum response when increasing rates of this element are applied (Painter, 1963; Molne, 1976; Baron *et al*., 1985; Tous *et al*., 1987). In the hazelnut orchard in Eastern Serbia (Zajecar), the leaf P content in cvs. Tonda Romana and Istarski Duguljasti was considerably lower (Miletic *et al*., 2001), i.e., more than twice lower than the content obtained in the present study. The results of the present study were confirmed by sufficient P contents for hazelnut leaves reported by Painter (1963), Childers (1973), Shear & Faust (1980), Molne (1976), Chaplin (1981), Lopez-Acevedo (1983), Kowalenko (1984) and Horuz & Korkmaz (2008), which suggested an optimal supply of the above nutrient in the leaf of the cultivars (Table 1).

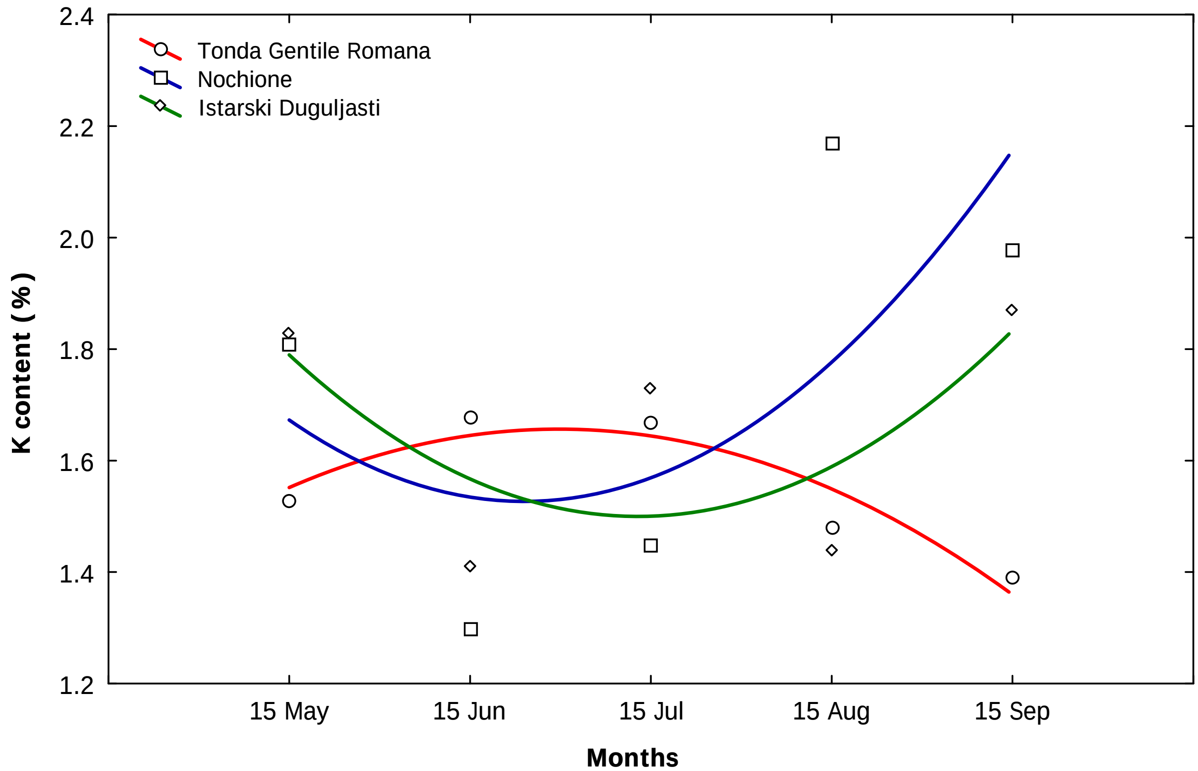

Fig. 3. The highest K content in cv. Tonda Gentile Romana was recorded at the beginning of the vegetative cycle, and that in cvs. Nochione and Istarski Duguljasti at the end of the cycle.

Content of potassium: The cultivar affected significantly ($p<0.01$) the potassium content of hazelnut leaves during the vegetative cycle, whereas the effects of the year and of the cultivar × year interaction were not significant (Table 1). The K content varied from 1.52±0.05 (Tonda Gentile Romana) to 1.77±0.04% (Nochione) among the cultivars and from 1.60±0.04 (2006) to 1.70±0.04% (2005) between the years. The absolutely highest leaf content of K was recorded in cv. Nochione in 2007 (1.80±0.04%). The highest K content at the beginning of the growing season was determined in cv. Tonda Gentile Romana and at the end of the season in cvs. Nochione and Istarski Duguljasti (Fig. 3). The most intensive K content dynamics during the vegetation cycle was exhibited by the leaf of the cv. Nochione, followed by Istarski Duguljasti and cv. Tonda Gentile Romana (CV=7.69%).

Of all the essential elements, potassium is the third most likely, after nitrogen and phosphorus, to limit plant productivity (Munshower, 1994). Potassium plays an important role in increasing the production quality and kernel size due to increasing assimilation of N in leaves (Painter & Hammer, 1963). The leaf K content in cv. Tonda Romana and Istarski Duguljasti in an orchard near Zajecar (Eastern Serbia) was considerably lower (Miletic *et al*., 2001). The present study revealed a much higher content of K as compared to the results reported by Painter (1963), Childers (1973), Shear & Faust (1980), Chaplin (1981) and Kowalenko (1984). The differences in K content were likely induced by the effect of internal (Canali *et al*., 2005) and external factors (Hart, 1986; Jones, 1993; Kowalenko, 1996; Adiloglu & Adiloglu, 2005; Horuz &Korkmaz, 2008).

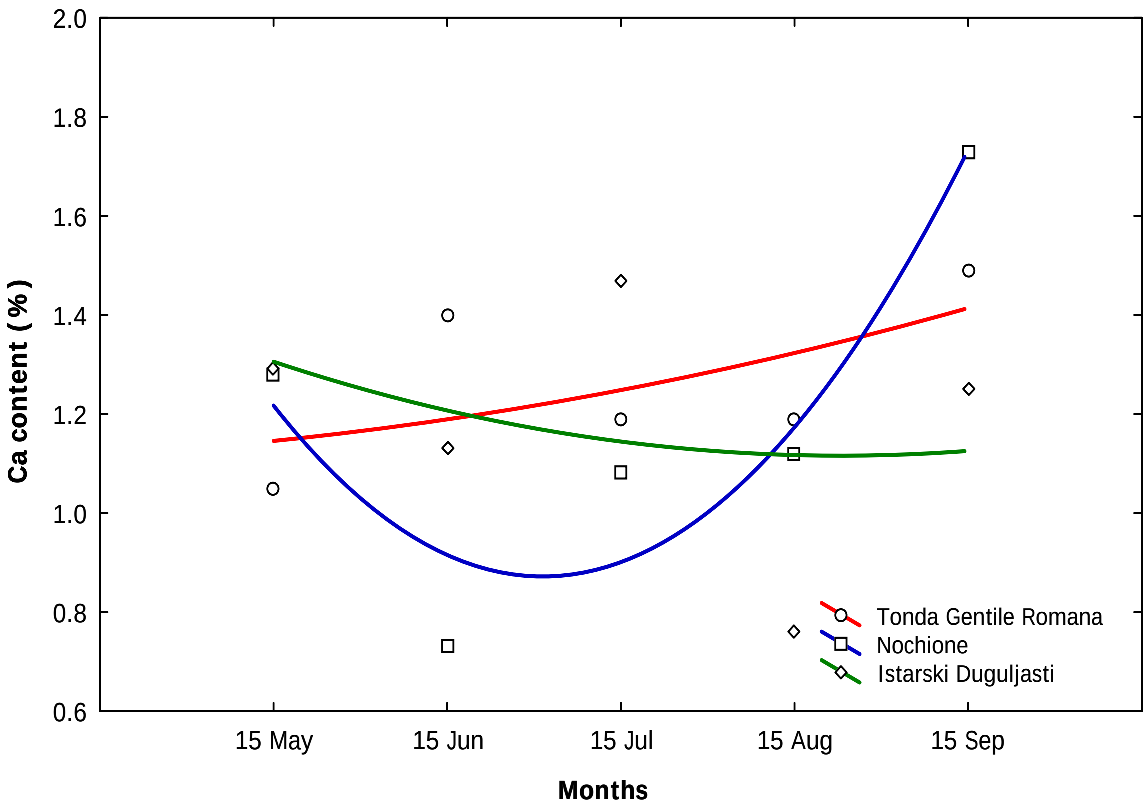

Fig. 4. The lowest Ca content in cvs. Nochione and Istarski Duguljasti was recorded in the mid-growing season, showing an increasing tendency at the end of the growing season. The content in cv. Nochione showed a continuously increasing tendency throughout the vegetative cycle.

Content of calcium: The content of calcium ranged from 1.12±0.08 (Nochione) to 1.27±0.07% (Tonda Gentile Romana) among the cultivars and from 1.20±0.07 (2006 and 2007) to 1.25±0.07% (2005) among the years. The highest leaf content of Ca was recorded in cv. Tonda Gentile Romana in 2007 (1.41±0.06%). However, the cultivar, the year and the cultivar × year interaction did not affect significantly the leaf content of calcium during the vegetative cycle (Table 1). The coefficient of variation was 8.83%. In the our study, the lowest leaf Ca content during the growing cycle in cvs. Nochione and Istarski Duguljasti was reported for the mid growing season, having a tendency to increase towards the end of the season. In cv. Nochione, it showed a continuous rising tendency throughout the growing season (Fig. 4), being consistent with the results obtained by Canali *et al*., (2005). A comparison of these results with those reported by Painter (1963), Childers (1973), Molne (1976), Shear & Faust (1980), Chaplin (1981), Kowalenko (1984) and Horuz & Korkmaz (2008), in terms of the optimum Ca content, suggested the optimum Ca supply of hazelnut leaves in this study (Table 1).

Content of magnesium: The cultivar, the year and the cultivar × year interaction affected significantly ($p<0.01$) the content of magnesium in hazelnut leaves during the vegetative cycle (Table 1). Mg content varied from 0.30±0.61 to 0.44±0.42% among the cultivars, the highest (0.44±0.42%) being obtained in the cv. Istarski Duguljasti, and from 0.35±0.52 (2006) to 0.37±0.49% (2005) between the years. The absolutely highest Mg content in our study was recorded in the leaf of cv. Istarski Duguljasti in 2005 and 2006 (0.47±0.39%). The Mg content exhibited the highest degree of variation as compared to the other elements examined (CV=18.19%).

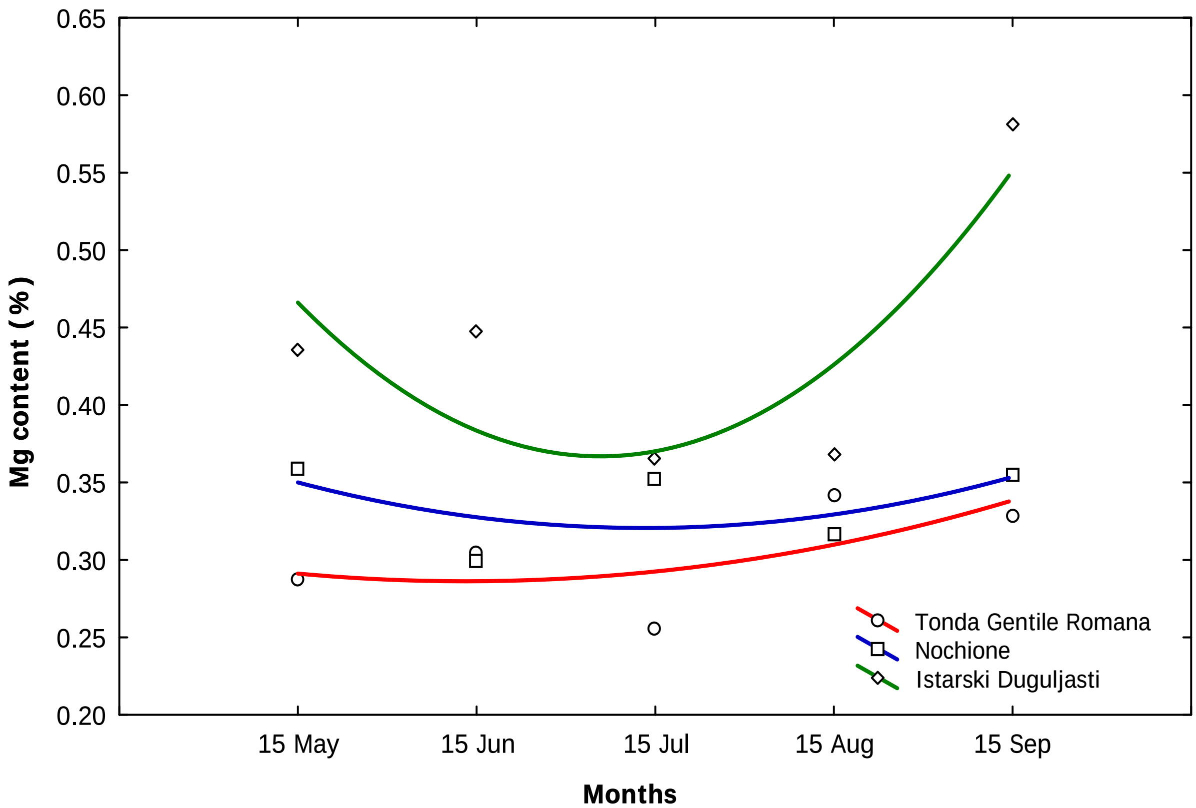

Fig. 5. The highest Mg content was recorded in cv. Istarski Duguljasti, its minimum and maximum being produced in July and at the end of the growing season, respectively. Similar tendency was registered with cv. Tonda Gentile Romana, though of lowest intensity. The highest and lowest contents in cv. Nochione were determined at the beginning and at the end of the growing season, respectively.

The most intensive Mg dynamics was recorded in the cv. Istarski Duguljasti, its minimum being in July, and maximum at the end of the growing season (Fig. 5). A similar tendency, though of lowest intensity, was exhibited by cv. Tonda Gentile Romana. The cv. Nochione produced the highest and lowest Mg contents at the beginning and at the end of the growing season, respectively. The differences in both the dynamics and average content of Mg were due to the effect of cultivars and overall pedoclimatic conditions (Canali *et al*., 2005; Kowalenko, 1996), as confirmed by ANOVA which showed that the differences in the average content resulted from a highly significant interactive effect of the cultivar and year. The sufficient Mg amounts in hazelnut plants reported by Painter (1963), Childers (1973), Molne (1976), Shear & Faust (1980), Chaplin (1981), Kowalenko (1984) and Horuz & Korkmaz (2008) served as a confirmation of the results of this study (Table 1).

In conclusion, the leaf contents of N, P, K, Ca and Mg in cvs. Tonda Gentile Romana, Nochione and Istarski Duguljasti grown under the environmental conditions of Western Serbia varied during the vegetative cycle. The highest effect on the content dynamics as well as on the average content was produced by the cultivar, i.e., genotype (Fig. 6), followed by the year and the cultivar × year interaction (Kowalenko, 1984; Adiloglu & Adiloglu, 2005; Canali *et al*., 2005; Horuz & Korkmaz, 2008). With this in mind, the results obtained in our study can be used to diagnose the nutritional status of hazelnut plants and to define the use of certain fertillizers in hazelnut orchards under similar environmental conditions.

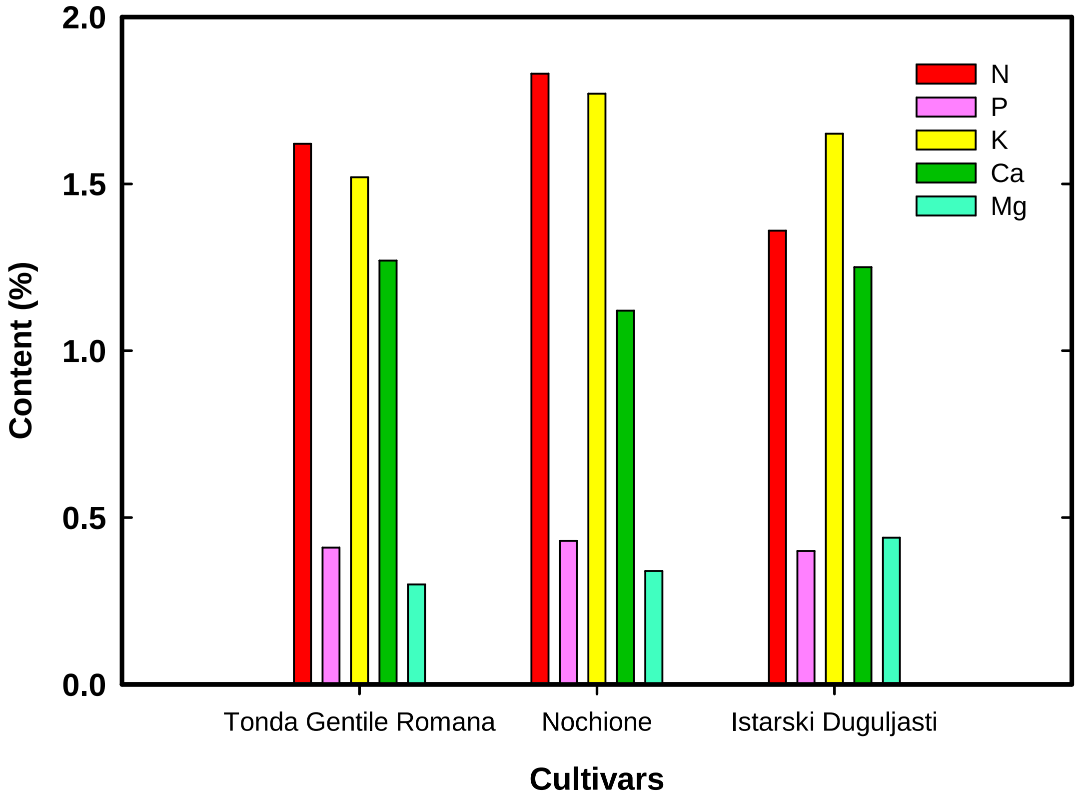

Fig. 6. Cultivar-dependent differences in the macronutrient content of hazelnut leaves: the highest average leaf contents of N (1.83±0.07%), P (0.43±0.09%) and K (1.77±0.04%) during the season were produced by cv. Nochione, and those of Ca (1.27±0.07%) and Mg (0.44±0.42%) by cvs. Tonda Gentile Romana and Istarski Duguljasti, respectively.

Acknowledgements

The authors are grateful to Ms. Jelena Krstic for her translation of the paper into English.

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(Received for publication 26 October 2008)