Macrominerals in Red Beet Root under Organic and Mineral Fertilization

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Summary

Nutritive value of food should be an imperativ and represents content of amino acids, vitamins, minerals, etc. Macrominerals (P, K, Ca, Mg) have an irreplaceable role in the functioning of living organisms and are part of all important biomolecules. Therefore, the goal of present research was to determine the influence of fertilization on content of macrominerals in red beet. A field trial (2003-2005) was set up in a hilly part of Croatia according to the Latin square method with four types of fertilization (control, 50 t stable manure ha^{-1}, 500 and 1000 kg NPK 5-20-30 ha^{-1}). Results show that the highest red beet phosphorus content was determined in treatment with stable manure. Higher level of applied potassium had depressing effect on calcium and magnesium uptake. By fertilization is possible to raise content of macrominerals in red beet, but it is recommended to apply combination of organic and mineral fertilizers.

Key words

Beta vulgaris var. *conditiva*, calcium, magnesium, phosphorus, potassium, vegetable

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Introduction

Global agricultural production is faced with great challenges. Increased human activity has become an important subject of debate in recent years. Rapid industrialization, intensive agricultural production and other anthropological activities lead to land and soil degradation, pollution and reduction of sustainability. This condition can only be solved by sustainable agriculture, which gives a considerable attention to the environment, based not so much on large investments, but on large knowledge about, among other things, the plant needs for nutrients, their quantities and transformations in soil, balanced fertilization, and the ability of plants to uptake and utilize nutrients (Bergmann, 1992). The issue of the optimal soil nutrients level is complex and varies depending on the overall soil properties as well as environmental and production factors of each individual plant species.

Today, great attention is not given just to a high yield in vegetable production, but also to the food quality and its nutritive value (Petek et al., 2012). Among a lot of different components in vegetables, macrominerals (P, K, Ca and Mg) have great importance, not only for the normal functioning of plants, but also of the people.

Phosphorous present in the soil is in organic or inorganic form. A large part of inorganic phosphorus, available to plants, is mainly present in the form of $H_2PO_4^-$ and HPO_4^{2-}. Availability of these ionic forms depends on the soil pH. At lower pH value more accessible is $H_2PO_4^-$ and at higher pH value more accessible is HPO_4^{2-} (Madhava Rao et al., 2006). Phosphorus binds to soil and is relatively immobile. Its availability in the soil solution, besides the above-mentioned pH, can be greatly reduced by organic matter as well as calcium and magnesium carbonates (Santos et al., 2004; Schenk, 2006). Phosphorus stimulates root growth, increases yield, water use efficiency and nutrient uptake, and influences the uptake of nitrogen and its metabolism through better root development (Bergmann, 1992; Madhava Rao et al., 2006; Mengel and Kirkby, 1987; Santos et al., 2004; Wang et al., 2008). Phosphorus prevents premature ripening of the leaves and helps the growth of young plants (Alvarez et al., 2001). Madhava Rao et al. (2006) reported that phosphorus deficiency affects less the root growth, but the shoots growth. Bergmann (1992) points out that plants, deficient in phosphorus, are stunted in growth and older leaves are characteristic blue-purple colored, because the lack of phosphorus stimulates the anthocyanins synthesis. Reduced tillage may require a higher phosphorus fertilization leading to increasing the soil phosphorus content (Pierzynski and Logan, 1993). Zhaohui and Shengxiu (2004) stated that the application of phosphorus fertilizer increased the yield of cabbage, but on spinach had no effect. Some authors (Ćustić et al., 2009; Herak Ćustić et al., 2007; Peck et al., 1980; Petek et al., 2008; Silber et al., 2003; Xu et al., 2004) in their studies highlight the positive effect of phosphorus fertilization on yield and phosphorus content in red beet, lettuce and chicory. Increasing application of phosphorus fertilizer has a positive effect on the availability of molybdenum (Lehoczky et al., 2005), but high soil phosphorus content can cause zinc deficiency in plants (Gianquinto et al., 2000; Kadar, 2000).

Potassium in plant is not part of the organic matter. It cannot be replaced by any other cation and has specific functions. It plays a central role in the growth and development of plants (Madhava Rao et al., 2006). Potassium ions are highly mobile in the xylem and phloem. Uptake of potassium increases, to maturity of the plant, until flowering. The yield is bigger by better potassium uptake (Wang et al., 2008; Alvarez et al., 2001; Subbarao et al., 2000). Due to the influence on ATP synthesis, potassium promotes the nitrogen uptake which for energy is required (Bergmann, 1992). It has been proven harmful effects of NH_4^+ ions on the potassium uptake (Marschner, 1995; Rafferty et al., 2004). Similarly, have proved Madhava Rao et al. (2006) who stated the overabundant potassium supply causes a nitrogen deficiency and can affect the divalent cations uptake such as Ca^{2+} and Mg^{2+} (ion antagonism).

The plants uptake calcium only in ionic form and transport it to the aboveground parts through the xylem by transpiration flow. Calcium is an integral part of a small number of organic molecules in the plant, but participates in the structure of cell membranes, reducing protoplasm hydratization and increase its viscosity, as well as in cell mitosis by preventing the abnormal nucleus division. In the central lamella calcium is bound to pectate, which is essential to the cell walls strength and tissues of the plant (Bergmann, 1992; Madhava Rao et al., 2006). Calcium excess in the growth medium interferes with the magnesium absorption and causes alkaline pH, which numerous micronutrients become unavailable to plant (Madhava Rao et al., 2006). Fenn and Taylor (1991) stated that the increasing of Ca^{2+}/NH_4^+ ratio significant increase yield of vegetables, especially root, which is confirmed by Bergmann (1992), who also emphasizes the importance of the ratio of calcium with potassium and magnesium. According to Bergmann (1992), calcium deficiency causes accumulation of nitrite (NO_2^-) because its intracellular transport is interrupted and plant cannot adopt nitrates. The cytosolic calcium is bound to a protein known as calmodulin that activates numerous enzymes such as NAD kinase and membrane ATPase (Madhava Rao et al., 2006).

Magnesium is the central atom of the chlorophyll molecule, and affects the synthesis of other pigments (carotenes and xanthophylls) and other organic molecules. According to Bergmann (1992) magnesium affects about 300 enzymatic reactions. Magnesium ions can be replaced by zinc, cobalt or calcium ions in a variety of reactions, but in many cases these ions are less effective. Stabilize the cell membrane and the cation balance inside and outside the cells. Magnesium ions are required for the activation of Na/K-ATPase which acts as an ion pump (Bergmann, 1992) and for the regulation of cellular pH (Madhava Rao et al., 2006). According to Austin et al. (1994) magnesium application can increase the dry matter content in the roots, stem and leaves, and the total plant weight is increased. Madhava Rao et al. (2006) stated that fertilization with fertilizers that contain large amounts of K^+ or NH_4^+ reduces magnesium uptake. Increasing the magnesium and manganese is conditioned by the increase in pH, which also reduces the toxicity and concentration of manganese in the leaves. Davis (1996) stated that the magnesium application results in a significant reduction in leaf manganese insufficiency. Magnesium deficiency reduces the production of phytohormones and nitrate reduction (Bergmann, 1992).

In table 1 are shown data for the macronutrient status of red beet founded in literature data.

Table 1. Red beet macronutrients content according to different sources (g kg^{-1} in dry matter)

Source	P	K	Ca	Mg
	g kg^{-1} in dry matter			
Botanical-online, 2009	3.2	26.0	1.3	1.8
Ekholm et al., 2007	1.8	26.1	1.0	1.6
Kołota and Adamczewska-Sowinska, 2006	3.7	24.9	1.2	–
Lešić et al., 2002	2.4-5.2	18.1-29.1	1.3-3.1	0.2-2.2
Lisiewska et al., 2006	2.2	21.3	1.6	1.5
Maynard and Hochmuth, 1997	3.7	24.9	1.2	–
Petek et al., 2008	2.5	–	–	–

The goal of present investigation was to determine the effect of application of organic and mineral fertilizers on macromineral content in red beet root.

Figure 1. Map of Croatia with highlighted locations of investigation (Brašljevica and Hrvatsko Polje)

Material and methods

Field work

A field fertilization trial with red beet (*Beta vulgaris* var. *conditiva*), cultivar 'Bikor', was laid out in Brašljevica and Hrvatsko Polje (Croatia) (figure 1) from 2003 to 2005 (Brašljevica in 2003: B-2003, Hrvatsko Polje in 2004: HP-2004 and Hrvatsko Polje in 2005: HP-2005) according to the Latin square method with four treatments (unfertilized control, 50 t stable manure ha^{-1}, and 500 and 1000 kg NPK 5-20-30 ha^{-1}). Untreated red beet seed was sown (22nd May 2003, 21st May 2004 and 29th June 2005) directly into soil and harvested (21st Aug 2003, 24th Aug 2004 and 28th Sep 2005) only once after about 90 days. Plant spacing was 0.07 m x 0.40 m; the main plot area was 12 m^2. Average mass of 1 red beet in 2003, 2004 and 2005 was 121, 230 and 200 g, respectively.

Chemical plant analysis

Dry homogenized samples of plant material (105°C) were analyzed in triplicate and the results are presented as mean values. After digestion of plant material with concentrated HNO_3 (MILESTONE 1200 Mega Microwave Digester) phosphorus was determined by spectrophotometer, potassium by flamephotometer and calcium and magnesium by atomic absorption spectrophotometer (AAS) (AOAC, 1995).

Chemical soil analysis

Investigations were performed on soil with soil reaction (pH_{H_2O}) of 6.1-6.6, with low to moderate humus and nitrogen content, poor in phosphorus and low to rich potassium content (table 2). Air-dried, grinded and homogenized soil was analyzed according to following methods: soil reaction (pH) was determined electrometricaly using combined electrode on pH-meter MA5730 in soil:water suspension with 1:2.5 ratio (w/v) (active acidity) (Škorić, 1982); humus by Tjurin method (JDPZ, 1966); potassium and phosphorus by Egner-Riehm-Domingo method (Egner et al., 1960); nitrogen by Kjeldahl method (AOAC, 1995).

Climate conditions

The closest meteorological station for Brašljevica is Jastrebarsko and for Hrvatsko Polje is Otočac.

Brašljevica, year 2003

The total precipitation throughout the year 2003 (graph 1a) was 766 mm, which is less than a multi annual average (935 mm, table 3). Precipitation during the vegetation months of red beet growing was 247 mm. Mean daily air temperature during the period of red beet growing were 19-23°C and were higher for 2 to 4°C in comparison to multi annual average (table 3). There was an arid period since the beginning of February, so plants were not able to use the water reserves from the soil, as well as above average daily temperature during that period. Generally, year 2003 was relatively unfavorable for red beet growing because of low precipitation and poor ratio of temperature and precipitation.

Table 2. Chemical properties of investigated soils

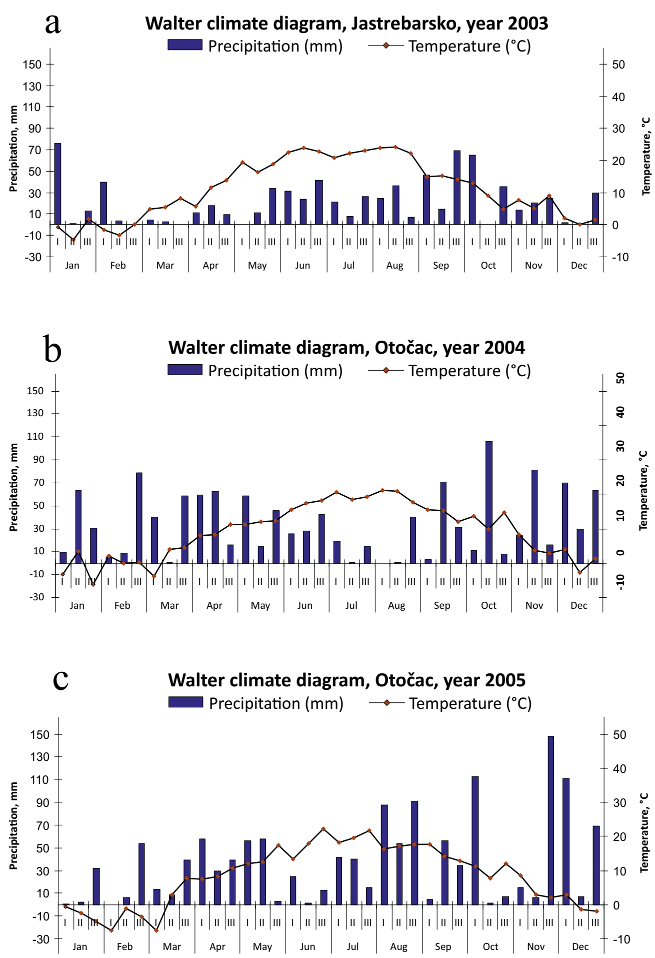
Environment	pH_{H2O}	humus	N	P_2O_5	K_2O
		%		AL – mg 100 g^{-1}	
B-2003	6.5	2.17	0.12	0.1	6.0
HP-2004	6.1	2.65	0.13	1.5	15.3
HP-2005	6.6	3.10	0.16	6.2	32.8

B-2003 – Brašljevica, year 2003; HP-2004 – Hrvatsko Polje, year 2004; HP-2005 – Hrvatsko Polje, year 2005

Table 3. Multi annual (1961-1991) climate data for meteorological stations Jastrebarsko and Otočac

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Jastrebarsko						
TMP	54	51	60	70	74	100	78	87	105	92	88	76
AMT	-0.4	1.1	5.9	10.6	15.6	18.7	20.7	20.2	15.6	10.8	4.9	0.9
						Otočac						
TMP	79	68	75	89	86	77	47	81	127	113	137	127
AMT	-1.0	0.1	3.9	8.9	14.1	17.8	19.7	19.0	13.9	10.5	5.0	0.1

TMP – total month precipitation (mm); AMT – average month temperature (°C)



Graph 1 (a, b and c). Walter climate diagrams for meteorological stations Jastrebarsko and Otočac

Hrvatsko Polje, year 2004

In year 2004 (graph 1b) weather conditions during the growing season were favourable for red beet growing thanks to the reserves of soil water before the growing, as well as to the rain during the first half of the growing period. Total precipitation during the year was 1238 mm, which is 133 mm higher than the multi annual average (1105 mm, table 3). Temperatures were lower, the ratio between temperature and precipitation was good and had favourable influence on the growth and development of red beet. Generally, temperatures were lower so there was not so much difference to the temperature and precipitation ratio what resulted with a favorable impact on the growth and development of red beet.

Hrvatsko Polje, year 2005

The total precipitation in year 2005 was 1339 mm and was higher for 234 mm than a multi annual average (1105 mm, table 3). Also, during the vegetation period (July-September) the total precipitation was 423 mm and was higher for 198 mm than a multi annual average (225 mm, table 3). Temperatures were favorable for the growth of red beet. During the whole growing period precipitation and temperature ratio was favorable, except in August, when fell 231 mm of precipitation, significantly more than required which could adversely affect the soil water-air ratio, and thus the red beet growth and minerals accumulation.

Comparing climatological conditions in all three investigation years during the growing period, it is evident that the most favorable conditions for normal growth and development of red beet prevailed in year 2004. Precipitation in 2003 was 247 mm and was poorly distributed. Temperatures were between 19°C and 23°C. In year 2004 was less precipitation (176 mm) during the red beet growth, air temperatures ranged from 17°C to 21°C, so this year was favorable for red beet growing because of favorable temperatures, and better distribution of precipitation. Air temperatures in year 2005 (15-20°C) were also within the biological optimum for the growth and development of red beet, but the precipitation were excessive (423 mm) so the weather conditions were unfavorable.

Statistical data analysis

Statistical data analysis were performed using the SAS 8.2 System (2002-2003). Tukey's multiple comparison test (Tukey's HSD, Tukey's Honestly Significant Difference test) was applied for the effects of fertilization and environment and their interactions, which in the analysis of variance was significant. Statistical level of significance for all analysis was defined as an error of 10% (with tags: $p<1\% = {}^{**}$; $p<5\% = {}^{*}$; $p<10\% = {}^{+}$).

Results

Table 4 shows the results of variance analysis for fertilization across the environments. Table 5 shows the results of the combined variance analysis in the three environments from which is evident that the weather conditions (environment) significantly affect the value of all studied macronutrients.

Table 4. Results of variance analysis for fertilization in the three environments for red beet root macronutrients content and significance levels[1]

Macronutrient (g kg^{-1} in dry matter)		Environment[2] B-2003	HP-2004	HP-2005
P	F exp[3]	2,55	3,69+	0,45
	Pr > F[4]	0,1517	0,0813	0,7283
K	F exp	0,24	2,29	1,82
	Pr > F	0,8689	0,1783	0,2447
Ca	F exp	3,26	1,78	0,75
	Pr > F	0,1014	0,2514	0,5612
Mg	F exp	2,30	2,89	0,41
	Pr > F	0,1772	0,1247	0,7531

[1] statistical significance level: + – p=10%; [2] B-2003 – Brašljevica, year 2003; HP-2004 – Hrvatsko Polje, year 2004; HP-2005 – Hrvatsko Polje, year 2005; [3] Fexp – F experimental factor; [4] Pr > F – error probability F factor

Table 5. The results of combined variance analysis in the three environments for red beet root macronutrients content and significance levels[1]

Macronutrient (g kg^{-1} in dry matter)		Fertilization	Environment	Environment* Fertilization
P	F exp[2]	6,14*	14,17**	0,47
	Pr > F[3]	0,0293	0,0067	0,8230
K	F exp	3,99	46,79**	0,51
	Pr > F	0,0703	<0,0001	0,7914
Ca	F exp	0,79	36,12**	2,39+
	Pr > F	0,5405	0,0003	0,0708
Mg	F exp	1,62	151,83**	1,83
	Pr > F	0,2821	<0,0001	0,1503

[1] statistical significance level: ** – p=1%; * – p=5%; + – p=10%; [2] Fexp – F experimental factor; [3] Pr > F – error probability F factor

Table 6. Red beet root phosphorus content (g P kg^{-1} in dry matter) regarding fertilization treatements and environments

Fertilization treatments	B-2003[x]	HP-2004	HP-2005	Average
	g P kg^{-1} in dry matter			
Control	2.0	1.7 b	3.7	2.5
50 t stable manure ha^{-1}	2.7	2.2 a	4.0	3.0
500 kg NPK ha^{-1}	2.0	2.0 ab	3.4	2.5
1000 kg NPK ha^{-1}	1.9	2.0 ab	3.7	2.5
Average	2.2 B[y]	2.0 B	3.7 A	

[x]B-2003 – Brašljevica, year 2003, HP-2004 – Hrvatsko Polje, year 2004; HP-2005 – Hrvatsko Polje, year 2005; [y]Factor level means accompanied by different letters are significantly different, with error p≤0.05 according to Tukey's HSD test. Small letters refer to fertilization treatments. Capital letters refer to average values of environments.

Table 7. Red beet root potassium content (g K kg^{-1} in dry matter) regarding fertilization treatements and environments

Fertilization treatments	B-2003[x]	HP-2004	HP-2005	Average
	g K kg^{-1} in dry matter			
Control	28.4	22.4	44.5	31.8
50 t stable manure ha^{-1}	29.1	25.9	47.9	34.3
500 kg NPK ha^{-1}	27.3	23.9	45.7	32.3
1000 kg NPK ha^{-1}	27.5	23.9	47.8	33.1
Average	28.1 B[y]	24.0 C	46.5 A	

[x]B-2003 – Brašljevica, year 2003, HP-2004 – Hrvatsko Polje, year 2004; HP-2005 – Hrvatsko Polje, year 2005; [y]Factor level means accompanied by different letters are significantly different, with error p≤0.05 according to Tukey's HSD test. Small letters refer to fertilization treatments. Capital letters refer to average values of environments.

Table 6 shows the average red beet root phosphorus content in dry matter. Considering the fertilization, relatively the highest phosphorus content was determined in Brašljevica in 2003 in the manure treatment (2.7 g P kg^{-1} in dry matter). In other fertilizer treatments 1.9 and 2.0 g P kg^{-1} in dry matter was determined. In Hrvatsko Polje in 2004 statistically significant phosphorus content (2.2 g P kg^{-1} in dry matter) was found in the treatment with 50 t manure ha^{-1}, but is not statistically significantly different from both mineral fertilization treatments (2.0 g P kg^{-1} in dry matter). The lowest phosphorus content was determined in unfertilized treatment (1.7 g P kg^{-1} in dry matter). In Hrvatsko Polje in 2005 relatively the highest phosphorus content (4.0 g P kg^{-1} in dry matter) again was determined when fertilizing with manure. According to the annual averages, it is clearly seen that, regardless the fertilization treatments, significantly more red beet root phosphorus in dry matter was found in Hrvatsko Polje in 2005 (3.7 g kg^{-1} P in dry matter), compared to Brašljevica (2003) and Hrvatsko Polje (2004) where 2.2 and 2.0 g of P^{-1} kg in dry matter, respectively, was determined. However, regardless the environment, fertilization with manure always achieved relatively the highest phosphorus content in the red beet root (3.0 mg P kg^{-1} in dry matter) compared to other treatments.

Table 7 shows the average red beet root potassium content in dry matter. In the first research environment (Brašljevica, 2003) potassium ranged from 27.3 to 29.1 g kg^{-1} K in dry matter and there was no statistical difference between the fertilization treatments. Relatively the highest value (29.1 g K kg^{-1} in dry matter) was found in treatment with stable manure. In second research environment (Hrvatsko Polje, 2004) relatively the highest potassium content was 25.9 g K kg^{-1} in dry matter (fertilization with 50 t ha^{-1} manure). Also, neither in Hrvatsko Polje in 2005 no statistical differences between fertilization was determined and again relatively the highest value was determined in the treatment with manure (47.9 g K kg^{-1} in dry matter). A significant difference was found between the annual average of red beet root potassium content in dry matter in relation to fertilizer treatments. The highest red beet root potassium content was found in Hrvatsko Polje in 2005 (46.5 g K kg^{-1} in dry matter), and the lowest in Hrvatsko Polje in 2004 (24.0 g K^{-1} kg in dry matter). Of all the fertilization treatments, fertilization with 50 t ha^{-1} of manure resulted in a relatively highest red beet root potassium content in dry matter in all three studied environments (average 34.4 g K kg^{-1} in dry matter).

Average red beet root calcium content in dry matter is shown in table 8. All values, regardless fertilization and environment ranged from 1.8 to 4.9 g Ca kg^{-1} in dry matter. Looking at the

Table 8. Red beet root calcium content (g Ca kg^{-1} in dry matter) regarding fertilization treatements and environments

Fertilization treatments	B-2003[x]	HP-2004	HP-2005	Average
	g Ca kg^{-1} in dry matter			
Control	4.1	2.5	2.7	3.1
50 t stable manure ha^{-1}	4.9	2.0	2.5	3.1
500 kg NPK ha^{-1}	4.0	1.8	2.5	2.8
1000 kg NPK ha^{-1}	4.1	2.1	2.6	2.9
Average	4.3 A[y]	2.1 C	2.6 B	

[x]B-2003 – Brašljevica, year 2003, HP-2004 – Hrvatsko Polje, year 2004; HP-2005 – Hrvatsko Polje, year 2005; [y]Factor level means accompanied by different letters are significantly different, with error p≤0.05 according to Tukey's HSD test. Small letters refer to fertilization treatments. Capital letters refer to average values of environments.

Table 9. Red beet root magnesium content (g Mg kg^{-1} in dry matter) regarding fertilization treatements and environments

Fertilization treatments	B-2003[x]	HP-2004	HP-2005	Average
	g Mg kg^{-1} in dry matter			
Control	6.9	2.3	2.4	3.9
50 t stable manure ha^{-1}	7.2	2.2	2.5	4.0
500 kg NPK ha^{-1}	6.2	2.1	2.4	3.6
1000 kg NPK ha^{-1}	5.9	2.0	2.5	3.5
Average	6.6 A[y]	2.2 B	2.5 B	

[x]B-2003 – Brašljevica, year 2003, HP-2004 – Hrvatsko Polje, year 2004; HP-2005 – Hrvatsko Polje, year 2005; [y]Factor level means accompanied by different letters are significantly different, with error p≤0.05 according to Tukey's HSD test. Small letters refer to fertilization treatments. Capital letters refer to average values of environments.

average annual calcium content significantly the most calcium content was found in Brašljevica in 2003 (average 4.3 g Ca kg^{-1} in dry matter), which is statistically significantly higher than in Hrvatsko Polje in 2004 (2.1 g kg^{-1} Ca in dry matter) and in Hrvatsko Polje in 2005 (2.6 g kg^{-1} Ca in dry matter). Fertilization with NPK through three investigated environments resulted in a relatively lower red beet root calcium content in dry matter (2.8 and 2.9 g Ca kg^{-1} in dry matter) compared to the control and manuring.

Table 9 presents the average values of red beet root magnesium content in dry matter. In Brašljevica in 2003 relatively the highest magnesium content was determined in fertilization with 50 t manure ha^{-1} (7.2 g Mg kg^{-1} in dry matter) and is not statistically different from the other fertilization treatments. Relatively the lowest magnesium content was determined in fertilization with 1000 kg NPK ha^{-1} (5.9 g Mg kg^{-1} in dry matter). In Hrvatsko Polje in 2004 no statistically difference in the magnesium content, considering the different fertilization, was determined and ranged between 2.0 and 2.3 g Mg kg^{-1} in dry matter. In the third research environment (Hrvatsko Polje, 2005) determined values of magnesium was amounted 2.4 and 2.5 g Mg kg^{-1} in dry matter. Between the annual average of the red beet root magnesium content in dry matter, a significant statistical difference was determined. The highest magnesium content was determined in Brašljevica in 2003 (6.6 g Mg kg^{-1} in dry matter), while in Hrvatsko Polje in 2004 and in Hrvatsko Polje in 2005 2.2 and 2.5 g of Mg^{-1} kg in dry matter, respectively, was determined. Fertilization with NPK in three studied environments resulted in average lower red beet root magnesium content in dry matter (3.6 and 3.5 g Mg kg^{-1} in dry matter) compared to the control and manuring.

Discussion

In this study, the statistical variations were found between the studied environments, but also between the fertilization treatments. So, in all three studied environments the highest red beet phosphorus content was determined in fertilization with manure (2.7, 2.2, and 4.0 g P kg^{-1} in dry matter, respectively). It is assumed that the mineralization of organic matter released some part of the phosphorus, because of the known fact that the part of the phosphorus is stored in the soil organic phase, and the second reason is better soil tightness, with of course, a favorable soil pH. Significantly more phosphorus was found in Hrvatsko Polje in 2005 in comparison to the other two environments, probably due to better initial supply of soil phosphorus. Determined red beet phosphorus content in this environment is in accordance with Kołota and Adamczewska-Sowinska (2006), Lešić et al. (2002) and Maynard and Hochmuth (1997) and higher than some other authors reported (Ekholm et al., 2007; Lisiewska et al., 2006).

In all three studied environments the highest red beet potassium content in dry matter was found in the fertilization treatment with stable manure (29.1, 25.9, and 47.9 g K kg^{-1} in dry matter, respectively). It is known that the potassium in the soil moves by diffusion, for which water is needed, probably secured by manure which further improved soil structure and soil water-air ratio.

Relatively the highest average values of calcium and magnesium in dry matter of red beet in all three environments were achieved in the control treatment and treatment with 50 t manure ha^{-1} compared to treatments with mineral fertilizers. By NPK fertilizer application a considerable amount of potassium was added. At the same time, uptake of calcium and magnesium was lower probably due to the known fact that they are antagonists with potassium (Bergmann, 1992; Madhava Rao et al., 2006). This theory is confirmed by the obtained results; the average lowest red beet root potassium content and the highest red beet content of calcium and magnesium in control unfertilized treatment were determined.

Conclusions

The results of this research have enabled more comprehensive understanding of different forms and doses of fertilizer in qualitative and quantitative terms. It was confirmed that fertilization, as an agriculture intervention, affects the red beet macronutrients content. Here, of course, has an important role also the quantity of each mineral in the soil before setting up the experiment (especially phosphorus and potassium). The highest average red beet phosphorus content in dry matter was determined in the treatment with 50 t stable manure ha^{-1}. The average lowest red beet potassium content and the highest red beet content of calcium and magnesium in control unfertilized treatment were determined due to antagonism.

Fertilization can increase red beet root macronutrients content, but it is not recommended to fertilize with NPK only, but also with other nutrients because of expressed antagonism of potassium with other cations. Regarding the achieved results, combined fertilization of 50 t stable manure ha^{-1} and 500 kg NPK 5-20-30 ha^{-1} is recommended, with the application of other nutrients, naturally, in order to avoid imbalance of nutrients in the soil and then in the plant.

References

Alvarez, C.E., Ortega, A., Fernández, M., Borges, A.A., 2001. Growth, yield and leaf nutrient content of organically grown banana plants in the Canary islands. Fruits. Vol. 56(1):17–26.

AOAC., 1995. Officinal method of analysis of AOAC International. 16th Edition, Vol. I, Arlington, USA.

Austin, M.T., Constantinides, M., Miyasaka, S.C., 1994. Effect of magnesium on early taro growth. Communications in Soil Science & Plant Analysis. 25(11-12):2159-2169.

Bergmann W., 1992. Nutritional disorders of plants. Gustav Fischer Verlag Jena, Stuttgart, New York.

Botanical-online., 2009. http://www.botanical-online.com/common-beet.htm, last access: 15/1/2012

Ćustić, M., Horvatić, M., Pecina, M., 2009. Nitrogen Fertilization Influences Protein Nutritional Quality in Red Head Chicory. Journal of Plant Nutrition. 32(4): 598-609 Davis J. G., 1996. Soil pH and magnesium effects on manganese toxicity in peanuts. Journal of plant nutrition. 19(3-4):535-550.

Davis, J.G., 1996. Soil pH and magnesium effects on manganese toxicity in peanuts. Journal of plant nutrition. 19(3-4):535-550.

Egner, H., Riehm, H., Domingo, W.R., 1960. Untersuchung über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nahrstoffzustanden der Boden. II, Chemische Extraktionsmethoden zur Phosphor und Kaliumbestimmung - K. Lantbr. Hogsk. Annir. W.R. 1960, 26: 199-215.

Ekholm, P., Reinivuo, H., Mattila, P., Pakkala, H., Koponen, J., Happonen, A., Hellström, J., Ovaskainen, M.-J., 2007. Changes in the mineral and trace element contents of cereals, fruits and vegetables in Finland. Journal of Food Composition and Analysis. 20:487–495.

Fenn, L.B., Taylor, R.M., 1991. Calcium stimulation of ammonium absorption in plants. Developments in agricultural and managed-forest ecology. 24(24):39-47.

Gianquinto, G., Abu-Rayyan, A., Di Tola, L., Piccotino, D., Pezzarossa, B., 2000. Interaction effects of phosphorus and zinc on photosynthesis, growth and yield of dwarf bean grown in two environments. Plant and Soil. 220:219-228.

Herak Ćustić, M., Petek, M., Toth, N., Poljak, M., Ćosić, T., 2007. Effects of organic and mineral fertilization on NPK status in soil and plant, and yield of red beet (*Beta vulgaris* var. *conditiva*. Cereal Research Communications. 35(2):449-452.

JDPZ, 1966. Priručnik za ispitivanje zemljišta. Knjiga I. Kemijske metode ispitivanja zemljišta, Beograd.

Kadar I., 2000. Effect of mineral fertilisation on the element uptake of maize (*Zea mays* L.) on chernozem soil, II. Novenytermeles. 49(1-2):128-140.

Kołota, E., Adamczevska-Sowińska, K., 2006. Burak ćwikłowy i liściowy. Hortpress, Warszawa, 12,16.

Lehoczky, E., Debreczeni, K., Szalai, T., 2005. Available micronutrient contents of soils in long-term fertilization experiments in Hungary. Communications in soil science and plant analysis. 36(4-6):423-430.

Lešić, R., Borošić, J., Buturac, I., Ćustić, M., Poljak, M., Romić, D., 2002. Povrćarstvo, Zrinski, Čakovec.

Lisiewska, Z., Kmiecik, W., Gebczynnski, P., 2006. Effects on Mineral Content of Different Methods of Preparing Frozen Root Vegetables. Food Science and Technology International, 12:497-503.

Madhava Rao, K.V., Raghavendra, A.S., Janardhan Reddy, K., 2006. Physiology and Molecular Biology of Stress Tolerance in Plants. Springer, Printed in the Netherlands, 187-217.

Marschner H., 1995. Mineral nutrition of higher plants. Academic Press Limited, San Diego, CA 92101.

Maynard, D.N., Hochmuth, G.J., 1997. Knott's Handbook for vegetable growers. John Wiley & sons, Inc. New York.

Mengel, K., Kirkby, E.A., 1987. Principles of Plant Nutrition. International Potash Institute, Bern.

Peck, N.H., Grunes, D.L., Welch, R.M., MacDonald, G.E., 1980. Nutritional quality of vegetable crops as affected by phosphorus and zinc fertilizers. Agronomy journal. 72(3):528-534.

Petek, M., Herak Ćustić, M., Čoga, L., Pecina, M., 2008. Phosphorus content in soil and in fresh and cooked red beet in dependence on different fertilization. Cereal Research Communications, Volume 36, Supplement, 435-438.

Petek, M., Herak Ćustić, M., Toth, N., Slunjski, S., Čoga, L., Pavlović, I., Karažija, T., Lazarević, B., Cvetković, S., 2012. Nitrogen and Crude Proteins in Beetroot (*Beta vulgaris* var. *conditiva*) under Different Fertilization Treatments. Notulae Botanicae Horti AgrobotaniciCluj-Napoca. 40(2):215-219.

Pierzynski, G.M., Logan, T.J., 1993. Crop, Soil, and Management Effects an Phosphorus Soil Test Levels. Journal of Production Agriculture. 6(4):513-520.

Rafferty, K., Davies, K.M., Heaney, R.P., 2004. Potassium intake and the calcium economy. Journal of the American College of Nutrition. 24(2 Suppl S):99-106.

Santos, B. M., Dusky, J.A., Stall, W.M., Gilreath, J.P., 2004. Effects of Phosphorus Fertilization on Common Lambsquarters (*Chenopodium album*) Duration of Interference in Lettuce. Weed Technology. Volume 18:179-183.

Schenk, M.K., 2006. Nutrient efficiency of vegetable crops. Acta horticulturae. 700:21-33.

Silber, A., Xu, G., Levkovitch, I., Soriano, S., Bilu, A., Wallach, R., 2003. High fertigation frequency: the effects on uptake of nutrients, water and plant growth. Plant and soil. 253(2):467-477.

Subbarao, G.V., Wheeler, R.M., Stutte, G.W., Levine, L.H., 2000. Low potassium enhances sodium uptake in red-beet under moderate saline conditions. Journal of Plant Nutrition. 23(10):1449-1470.

Škorić, A., 1982. Priručnik za pedološka istraživanja. Fakultet poljoprivrednih znanosti, Zagreb.

Wang, Z.-H., Li, S.-X., Malhi, S., 2008. Effects of fertilization and other agronomic measures on nutritional quality of crops. Journal of the science of food and agriculture. 88(1):7-23.

Xu, G., Levkovitch, I,. Soriano, S., Wallach, R., Silber, A., 2004. Integrated effect of irrigation frequency and phosphorus level on lettuce: P uptake, root growth and yield. Plant and soil. 263(1-2):297-309.

Zhaohui, W., Shengxiu, L., 2004. Effects of nitrogen and phosphorus fertilization on plant growth and nitrate accumulation in vegetables. Journal of plant nutrition. 27(3):539-556.

acs81_29