MINERAL RATIOS IN BEETROOT UNDER DIFFERENT FERTILIZATION

Marko Petek, Nina Toth, Marija Pecina, Tomislav Karažija, Boris Lazarević, Mirjana Herak Ćustić

University of Zagreb, Faculty of Agriculture, Croatia

Corresponding author: mpetek@agr.hr

Abstract

Besides the absolute values of mineral content in plant tissue, particularly is important their relative relationship. Imbalance in nutrient uptake very often is result of extensive fertilization with one nutrient, which is then in excess, so can prevent uptake of other nutrients what may cause disturbances in metabolism. Therefore, the goal of present research was to determine the influence of fertilization on mineral ratios in beetroot. 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). Some investigated ratios ranged as follows: N+P+K 4.08-8.17, K+Ca+Mg 2.83-5.14, K/Ca 6.8-18.1, K/Mg 4.3-19.3, K/(Ca+Mg) 2.6-9.3, (N+P)/K 0.70-1.26, Ca/P 0.7-2.0, Ca/Mg 0.65-1.07, K/Mn 297-789, N/Zn 501-786, P/Zn 41-92, Fe/Mn 1.6-2.8, Fe/Cu 11-23, Fe/(Cu+Zn) 2.1-4.2, Zn/Cu 3.3-7.6, Mn/Zn 1.5-1.8, Mn/Fe 0.38-0.62. In order to achieve high mineral content and its favorable ratio is necessary to combine the organic and mineral fertilizers with foliar fertilization.

Keywords: *Beta vulgaris* var. *conditiva* Alef., iron, manganese, nutrient, phosphorus.

Introduction

Both, macro and micronutrient plant content, should be within a range referred to as sufficient for a productive plant production. Mineral and organic fertilization affects both, vegetative and reproductive organs, but what is more important yield quantity and quality, which is nowdays very important issue. If the plant mineral content is below the optimum range the plant might suffer from excessive or deficient content of nutrients that reduce the yield quantity and quality. To avoid this situation the optimal fertilization design should be applied according to plant needs as well as nutrient soil status. In addition to the optimal content of minerals in soil and plant tissue, relative ratio of minerals is particularly important (Bergmann, 1992). It is commonly known that between ions two types of relations are dominated, antagonism and synergism. The imbalance in nutrient uptake is very common where the abundant fertilization of one single nutrient was appliled which is then in surplus and therefore block the uptake of another nutrient which can cause metabolic disorders(Marschner, 1995). The nutrient soil application has to be adapted to the planned production to ensure the annual need for normal growth and development of plants (Karažija, 2013). However, special attention should be paid to the balance of nutrition, as increased doses of mineral fertilizers can cause problems (Miljković and Bišof, 1988, cited by Drenjančević, 2011). Initially, the ratio of minerals was attempted to evaluate on the basis of the plant tissue mineral content and its limit values (Bergmann, 1992). Later, evaluation of N-P-K was performed, and then to a number of other ratios among biogenic elements, which better indicated harmony in plant nutrition. It was followed by the representation of certain elements in a triangular percentage, and in particular for nitrogen, phosphorus, potassium, calcium and magnesium. Then the intensity of nutrition was expressed as the sum of cations (K+Ca+Mg). Recent studies have shown that great attention should be paid to cations, especially potassium, calcium and magnesium (Ćosić i sur., 2010) although the ratio both beetwen microelements, as well as macro and microelements becoming more and more interesting (Ryser, 1982; Pitura and Michalojc, 2015; Murawska et al., 2013; Krzywy and Krzywy, 2001; Tariq and Mott, 2006; Jarnuszewski and Meller, 2013).

Therefore, the aim of this researach was to determine and evaluate the effect of organic and mineral fertilization of red beet on mineral ratios.

Material and methods

Field work

A field fertilisation trial with beetroot (*Beta vulgaris* var. *conditiva* Alef.), cultivar 'Bikor', was carried out in Brašljevica and Hrvatsko Polje (Croatia) from 2003 to 2005 (Brašljevica in 2003, B-2003; Hrvatsko Polje in 2004, HP-2004 and Hrvatsko Polje in 2005, HP-2005) using the Latin square method with four treatments (unfertilised control, 50 t stable manure ha^{-1}, 500 and 1000 kg NPK 5-20-30 ha^{-1}). Untreated beetroot seed was sown (22nd May 2003, 21st May 2004 and 29th June 2005) directly into soil with a plant spacing of 0.07 m x 0.40 m and a main plot area of 12 m^2. Beetroot were harvested (21st Aug 2003, 24th Aug 2004 and 28th Sep 2005) after ~90 days.

Chemical plant analysis

The edible parts of six plants from each plot at harvest were randomly selected for analyses. Samples of plant material (dried at 105°C) were analysed in triplicate and the results presented as mean values. After digestion of plant material with concentrated HNO_3 (MILESTONE 1200 Mega Microwave Digester), phosphorus was determined spectrophotometrically, potassium by phlamephotometer, calcium, magnesium, iron, manganese, copper and zinc were analysed by an atomic absorption spectrophotometer (AAS) (AOAC, 1995).

Chemical soil analysis

Field investigations were carried out on silty loam soil with a soil reaction (pH_{H2O}) of 6.1-6.6, with low to moderate humus and nitrogen content, poor in phosphorus and low to rich in potassium (Table 1). Air-dried, ground and homogenized soil was analysed according to following methods: soil pH was determined electrometrically using a combined electrode (pH-meter MA5730) for a soil:water suspension (1:2.5, w/v) (active acidity) (Škorić, 1982); humus by the Tjurin method (JDPZ, 1966); potassium and phosphorus by the Egner-Riehm-Domingo method (Egner et al., 1960) and nitrogen by Kjeldahl method (AOAC, 1995).

Table 1. Chemical properties of the soils collected

		%	%	AL – mg 100 g^{-1}	
Environment[x]	pH_{H2O}	humus	N	P_2O_5	K_2O
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

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

Comparing climatological conditions in all three investigation years during the growing period, it is evident that the most favourable 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 favourable for red beet growing because of favourable 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 was excessive (423 mm) so the weather conditions were unfavourable.

Results and discussion

As was discussed earlier, at the begining of thinking about mineral ratios, sum of some nutrients was discussed first. So, regarding both sum of nutrients (N+P+K) and (K+Ca+Mg) fertilization treatments did not affected, but environment did (Tables 2 and 3). Statisticaly the highest sum of nutrients was determined in humid environment HP-2005 (8.17 and 5.14, respectively) and was higher than Ryser (1982) reported (3.92-4.54 and 4.23-4.91, respectively) and Neyroud et al. (2007) reported (4.27 and 3.47, respectively).

Ratio beetwen two antagonistic cations (Bergmann, 1992) is very important. Again, the lowest ratio in dry season is determined because of lack of water which is important for Ca uptake (Table 4). All fertilization treatments statisticaly incerased the ratio (11,3-13,1) compared to control treatment in HP-2004 environment (with favourable climate conditions). However, statisticaly the highest K/Ca ratio was determined in HP-2005 environment (18,1) compared to other two environments which can be explained by leaching of Ca due to excess of rainfall (Petek, 2009). Our results are much higher than literature reported (Pitura and Michalojc (2015) reported 2-4 as optimal K/Ca ratio) which can be explained with relatively high soil potassium content, especially in HP-2004 and HP-2005 environments (Table 1).

Table 5 shows K/Mg ratio in red beet root. Similar situation, as with K/Ca ratio, has been determined with this ratio too. Again, all fertilization treatments had statistical effect on K/Mg ratio in season with favourable climate condition (HP-2004) that ranged from 11,3 to 12,2. In other two environments fertilization tratments had no effect due to lack or excess of water. There are different literature dana regarding the optimal K/Mg ratio. Ryser (1982) reported optimal range from 6.8 to 7.9, and Pitura and Michalojc (2015) from 2 to 6 cited from other literature, but in their own results reported mostly 10-20 in lettuce, curly kale and celery. Our findings showed high ratio in HP-2004 and especially in HP-2005 environments probably due to high potassium soil content (Table 1) which suggest very low uptake of magnesium of very low magnesium soil level.

Ratio of cations K/(Ca+Mg) is also important for optimal plant growth (Table 6). Again, the trend of this ratio is the same as in previous mentioned ratios with potassium. There are different data regarding the K/(Ca+Mg) ratio. According to different authors cited in Pitura and Michalojc (2015) optimal ration is 1.62-2.2, although they reported up to 4.02, while Murawska et al. (2013) reported very low ratios, from 0.62 to 0.77, as well as Ryser (1982) from 0.58 to 0.66. Our results showed statisitcaly higher ratio of cations in HP-2004 and HP-2005 environtments. On the other side, the situation is complitely oposite when the ratio is calculated by dividing by potassium – (N+P)/K (Table 7). Even thoug there is sum of different nutirents, the trend is the same. Statisticaly the highest ratio is determined in dry season in B-2003 environment (1.26) and is lower than reported by Ryser (1982) of 1.30-1.50. Obviously, potassium is prevailed cation in investigated soil and so in uptake by plant too. Unfavourable climate conditions had greater effect on nutrient uptake than the fertilization treatments, so in HP-2004 effect of fertilization was determined only.

Table 8 shows the Ca/P ratio in red beet root. Fertilization treatment statisticaly significant affected Ca/P ratio in HP-2004 environment only, when climate conditions were optimal. In other two environments (dry and humid) effect of fertilization was not statisticaly affected Ca/P ratio. The statisticaly highest ratio was obtained in B-2003 environtment (2,0) in dry season when uptake of phosphorus was at low level due to lack of water in rizosphere which is very important for phosphorus soil mobility because phosphorus is transporte din soil mostly by difussion (Mengel and Kirkby, 1987). Murawska et al. (2013) reported very low Ca/P ratio in maize grain (0.14-0.21). Optimal ratio according to Pitura and Michalojc (2015) is 2.0. Our findings are similar to this value just in dry season, which suggest that in season of favourable climate condition uptake of Ca was low, probably due to low calcium soil content according to soil type. As we reported in our previous paper (Petek et al., 2016), in humid environment (HP-2005) the highest red beet root phosphorus content was determined (3,7 g P kg^{-1}) and the highest calcium content in dry environment (B-2003, 4,0 g Ca kg^{-1}).

In Table 9 are shown results of Ca/Mg ratios that ranged from 0.60 to 1.16. In humid HP-2005 environment determined ratio was statisticaly significant the highest (1.07) and was much higher than Murawska et al. (2013) reported (0.27-0.46).

Potassium had the same effect on uptake of micronutrient manganese. The average highest K/Mn ratio (789) was determined in humid HP-2005 environment (Table 10) where is high soil potassium content. In all three environments the fertilization treatment increased the value of K/Mn ratio compared to unfertilized treatment, in B-2003 and HP-2005 this increase was statisticaly significant. Bergmann (1992) reported 225 as optimal K/Mn ratio, Ekholm et al. (2007) 870 and Lisiewska et al. (2006) 789. In our research the ratios are determined in very wide range, from 297 up to 789. Low ratio suggest low potassium uptake and high ratio suggest low manganese uptake. As manganese is one of important microelement, both in plant and human metabolism, we suggest as optimal ratio about 500, which realised in HP-2004 environment when favourable climate condition performed. By consutling our previous work (Petek et al., 2016), these result of ratios with potassium are highly expected, especially in HP-2005 environment because, not just that there was high soil potassium content, but also there was high red beet root potassium content (47 mg K kg^{-1}).

The ratio of N/Zn is shown in Table 11. All values are a lot below recommended value of 1200, reported by Bergmann (1992). Here can be determined similar situation as with K/Mn ratio regarding the effect of fertilization treatments and effect of environments. Again in HP-2005 environment statisticaly the highest N/Zn ratio (786) was deterined. But, as in first two years of investigation N/Zn ratio was quite low, better nitrogen fertilization is needed as Petek et al. (2016) reported quite high zinc content, especially in B-2003 of 53 mg Zn kg^{-1}.

Generaly, fertilization treatment had positive effect on P/Zn ratio (Table 12) compared to control treatment, but environment had great effect on P/Zn ratio too. The highest ratio was determined in humid season (HP-2005) probably due to relatively good phosphorus uptake in this season. This assumption is backed up with our previous work (Petek et al., 2016) which reported 3,7 g P kg^{-1} in red beet root. However, all values are much lower than reported by most literature. Bergmann (1992) reported P/Zn ratio of 110 as optimal, Ekholm et al. (2007) 113 and Kadar (2000) lower than 200. Only Lisiewska et al. (2006) reported 54 which is relatively similar as we determined in dry season, so we think that, bue to lack of water, this value is not the optimal one.

Discussing about ratios beetwen microelements (Fe/Cu, Fe/(Cu+Zn), Zn/Cu, Mn/Zn and Mn/Fe) (Tables 13-18) it can be observed the similar trend. Mostly, the fertilization treatments had no statisticaly significant effect on micronutrients ratios. According to literature data of ratios with Fe [recomended Fe/Cu ratio by Pitura and Michalojc, (2015) is 6-19 and 15.8-29.2 reported by Tariq and Mott (2006)], it can be concluded that red beet had no problems with Fe uptake which very well proved that red beet is rich in iron, as we already reported in our paper (96-270 mg Fe kg^{-1}) (Petek et al., 2016). The ratios beetwen micronutrients in plants reporetd in literature: Zn/Cu 4.9-16.9, Mn/Zn 0.43-5.8, Mn/Fe 0.21-2.5 (Pitura and Michalojc, 2015; Tariq and Mott, 2006). in the present research mentioned ratios are as follows: 3.3-4.2, 1.5-1.8 and 0.38-0.62, respecitvely. Bergmann (1992) reported that abundant fertilization with nitrogen can cause a lack of potassium in the plant and that also magnesium, manganese, iron and zinc content must be balanced to favorably affect the metabolic processes in the plant. So, it is not always important to achieve the highest mineral ratio, because it menas that the second nutrient i sin low level in plant tissue. So, we always have to keep in mind the optimum levels of all nutrients.

Table 2. N+P+K ratio in red beet root dry weight according to fertilizations and years of environments

	N+P+K ratio, based on % in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	6.28	3.85	7.92 b	6.01
Stable manure, 50 t ha^{-1}	6.60	4.27	8.36 ab	6.41
500 kg NPK ha^{-1}	6.11	4.08	7.93 b	6.04
1000 kg NPK ha^{-1}	6.19	4.13	8.49 a	6.27
Average	6.30 B[2]	4.08 C	8.17 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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 3. K+Ca+Mg ratio in red beet root dry weight according to fertilizations and years of environments

	K+Ca+Mg ratio, based on % in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	3.94	2.72	4.96	3.87
Stable manure, 50 t ha^{-1}	4.12	3.00	5.28	4.14
500 kg NPK ha^{-1}	3.75	2.78	5.06	3.86
1000 kg NPK ha^{-1}	3.75	2.80	5.28	3.94
Average	3.89 B[2]	2.83 C	5.14 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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 4. K/Ca ratio in red beet root dry weight according to fertilizations and years of environments

	K/Ca ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	7.2	9.4 b	16.5	11.0
Stable manure, 50 t ha^{-1}	6.0	13.1 a	19.2	12.8
500 kg NPK ha^{-1}	6.8	13.1 a	18.5	12.8
1000 kg NPK ha^{-1}	7.1	11.3 ab	18.3	12.2
Average	6.8 C[2]	11.7 B	18.1 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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 5. K/Mg ratio in red beet root dry weight according to fertilizations and years of environments

	K/Mg ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	4.1	9.7 b	19.0	11.0
Stable manure, 50 t ha^{-1}	4.0	12.1 a	19.2	11.8
500 kg NPK ha^{-1}	4.4	11.3 ab	19.3	11.7
1000 kg NPK ha^{-1}	4.7	12.2 a	19.5	12.1
Average	4.3 C[2]	11.3 B	19.3 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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. K/(Ca+Mg) ratio in red beet root dry weight according to fertilizations and years of environments

	K/(Ca+Mg) ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	2.6	4.8 b	8.8	5.4
Stable manure, 50 t ha^{-1}	2.4	6.3 a	9.6	6.1
500 kg NPK ha^{-1}	2.7	6.0 a	9.4	6.1
1000 kg NPK ha^{-1}	2.8	5.8 a	9.4	6.0
Average	2.6 C[2]	5.7 B	9.3 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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. (N+P)/K ratio in red beet root dry weight according to fertilizations and years of environments

	(N+P)/K ratio, based on % in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	1.22	0.72 a	0.79	0.91
Stable manure, 50 t ha^{-1}	1.27	0.65 b	0.75	0.89
500 kg NPK ha^{-1}	1.24	0.70 ab	0.74	0.90
1000 kg NPK ha^{-1}	1.29	0.73 a	0.79	0.94
Average	1.26 A[2]	0.70 B	0.77 B	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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 8. Ca/P ratio in red beet root dry weight according to fertilizations and years of environments

	Ca/P ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	2.1	1.6 a	0.8	1.5
Stable manure, 50 t ha^{-1}	1.8	1.0 b	0.6	1.2
500 kg NPK ha^{-1}	2.0	1.0 b	0.7	1.3
1000 kg NPK ha^{-1}	2.2	1.2 ab	0.7	1.4
Average	2.0 A[2]	1.2 B	0.7 C	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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. Ca/Mg ratio in red beet root dry weight according to fertilizations and years of environments

	Ca/Mg ratio, based on % in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	0.60	1.05	1.16	0.94
Stable manure, 50 t ha^{-1}	0.67	0.92	1.00	0.86
500 kg NPK ha^{-1}	0.66	0.87	1.05	0.86
1000 kg NPK ha^{-1}	0.69	1.09	1.08	0.95
Average	0.65 C[2]	0.98 B	1.07 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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 10. K/Mn ratio in red beet root dry weight according to fertilizations and years of environments

	K/Mn ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	268 b[2]	491	726 b	495
Stable manure, 50 t ha^{-1}	352 a	636	840 a	609
500 kg NPK ha^{-1}	274 ab	544	794 ab	537
1000 kg NPK ha^{-1}	293 ab	588	796 ab	559
Average	297 C	565 B	789 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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 11. N/Zn ratio in red beet root dry weight according to fertilizations and years of environments

	N/Zn ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	545 b[2]	481	758 b	595
Stable manure, 50 t ha^{-1}	698 a	501	788 ab	662
500 kg NPK ha^{-1}	583 ab	474	738 b	598
1000 kg NPK ha^{-1}	695 a	548	862 a	702
Average	630 B	501 C	786 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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 12. P/Zn ratio in red beet root dry weight according to fertilizations and years of environments

	P/Zn ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	33 b[2]	57 b	90	60
Stable manure, 50 t ha^{-1}	55 a	75 a	99	76
500 kg NPK ha^{-1}	37 ab	62 ab	84	61
1000 kg NPK ha^{-1}	39 ab	69 ab	96	68
Average	41 C	66 B	92 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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 13. Fe/Mn ratio in red beet root dry weight according to fertilizations and years of environments

	Fe/Mn ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	2.9	2.4	1.6	2.3
Stable manure, 50 t ha^{-1}	3.3	2.5	1.7	2.5
500 kg NPK ha^{-1}	2.7	2.2	1.6	2.2
1000 kg NPK ha^{-1}	2.4	2.4	1.6	2.1
Average	2.8 A[2]	2.4 B	1.6 C	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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 14. Fe/Cu ratio in red beet root dry weight according to fertilizations and years of environments

	Fe/Cu ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	26	12	18	19
Stable manure, 50 t ha^{-1}	23	11	18	18
500 kg NPK ha^{-1}	23	11	19	17
1000 kg NPK ha^{-1}	19	11	18	14
Average	23 A[2]	11 C	18 B	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005
[2]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 15. Fe/(Cu+Zn) ratio in red beet root dry weight according to fertilizations and years of environments

	Fe/(Cu+Zn) ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	4.4	2.8	2.1	3.1
Stable manure, 50 t ha^{-1}	4.6	2.6	2.1	3.1
500 kg NPK ha^{-1}	4.1	2.5	2.0	2.9
1000 kg NPK ha^{-1}	3.8	2.6	2.2	2.9
Average	4.2 A[2]	2.6 B	2.1 B	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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 16. Zn/Cu ratio in red beet root dry weight according to fertilizations and years of environments

	Zn/Cu ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	5.0 a[2]	3.4	7.5 b	5.3
Stable manure, 50 t ha^{-1}	4.3 ab	3.1	7.5 b	5.0
500 kg NPK ha^{-1}	4.7 ab	3.6	8.1 a	5.5
1000 kg NPK ha^{-1}	3.9 b	3.0	7.4 b	4.8
Average	4.5 B	3.3 C	7.6 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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 17. Mn/Zn ratio in red beet root dry weight according to fertilizations and years of environments

	Mn/Zn ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	1.8	1.6	1.5 ab	1.6
Stable manure, 50 t ha^{-1}	1.7	1.5	1.4 bc	1.5
500 kg NPK ha^{-1}	1.9	1.4	1.4 c	1.6
1000 kg NPK ha^{-1}	2.0	1.5	1.5 a	1.7
Average	1.8 A[2]	1.5 B	1.5 B	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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 18. Mn/Fe ratio in red beet root dry weight according to fertilizations and years of environments

	Mn/Fe ratio, based on mg kg^{-1} in DW			
Treatments	B-2003[1]	HP-2004	HP-2005	Average
Control	0.35	0.43	0.64	0.47
Stable manure, 50 t ha^{-1}	0.32	0.43	0.60	0.45
500 kg NPK ha^{-1}	0.40	0.45	0.62	0.49
1000 kg NPK ha^{-1}	0.44	0.42	0.62	0.49
Average	0.38 B[2]	0.43 B	0.62 A	

[1]Environments: B-2003 – Brašljevica in 2003; HP-2004 – Hrvatsko Polje in 2004; HP-2005 – Hrvatsko Polje in 2005

[2]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.

Conclusions

Organic and mineral fertilization affected mineral ratios, especially in season with favourable climate conditions. Agroecologial conditions affecte too on mineral ratios during 3-year field trial. Although, it can be concluded that potassium dominates in treatments fertilized with NPK, especially with 1000 kg NPK ha-1, results showed antagonistic effect on other nutrients just in humid season. Based on obtained results it can be concluded that during the dry season deficiency of P, Mg and Zn can be expected, and during the humid season surplus of potassium can be obtained. So producers should be prepared, besides basic soil fertilization, to perform foliar fertilization with mentioned nutrients on time, to aviod deficiencies caused by low nutrient uptake in dry season, or to avoid antagonism with potassium in humid seasons.

References

1. AOAC. (1995). Officinal method of analysis of AOAC International. 16th Edition, Vol. I, Arlington, USA.
2. Bergmann W. (1992). Nutritional disorders of plants. Gustav Fischer Verlag Jena, Stuttgart, New York.
3. Ćosić, T., Karažija, T., Čoga, L., Petek, M., Poljak, M., Herak Ćustić, M., Jurkić, V., Pavlović, I. and Slunjski, S. (2010). Istraživanje biljno hranidbenog kapaciteta vinograda u Bolu folijarnom analizom, Study, Department of Plant Nutrition, Zagreb.
4. Egner, H., Riehm, H. and 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.
5. Ekholm, P., Reinivuo, H., Mattila, P., Pakkala, H., Koponen, J., Happonen, A., Hellström, J. and 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.
6. Neyroud, J. A., Amiguet, S., Andrey, G. and Evequoz, Ch. (2007). Le diagnostic foliaire en arboriculture: bilan de 20 ans d'étude. Revue suisse Vitic. Arboric. Hortic. 39 (5): 307-313.
7. Jarnuszewski, G. and Meller, E. (2013). Mineral element ratios in plants grown on post-bog soil fertilized with zinc and copper. Fol. Pomer. Univ. Technol. Stetin., Agric., Aliment., Pisc., Zootech., 304 (26): 25-32.
8. JDPZ (1966). Priručnik za ispitivanje zemljišta. Knjiga I. Kemijske metode ispitivanja zemljišta, Beograd.
9. 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.
10. Karažija, T. (2013). Utjecaj organskih gnojiva na ishranjenost, prinos i kvalitetu grožđa cv. Sauvignon bijeli na karbonatnim tlima. PhD thesis, Zagreb.
11. Krzywy, E. and Krzywy, J. (2001). The N:S and Fe:Mn ion ratios as factors indicative of the quality of crop plants obtained under the Waste 7, sulfate hydrate (VI) iron (II). Fol. Univ. Stetin., 221 Agric. 88, 133-140.
12. Lisiewska, Z., Kmiecik, W. and Gebczynnski P. (2006). Effects on Mineral Content of Different Methods of Preparing Frozen Root Vegetables. Food Science and Technology International, 12:497-503.
13. Marschner, H. (1995). Mineral nutrition of higher plants. Academic Press Limited, San Diego, CA 92101.
14. Mengel, K. and Kirkby, E. A. (1987). Principles of Plant Nutrition. International Potash Institute, Bern.
15. Drenjančević. M. (2011). Fe-kloroza vinove loze na podunavskoj regiji. PhD thesis, Osijek.
16. Murawska, B., Spychaj-Fabisiak, E., Knapowski, T. and Głowacki B. (2013). Ionic equilibrium in maize grain depending on the fertilisation and soil type. Journal of Central European Agriculture, 14(4): 1518-1529.

17. Petek, M., Toth, N., Pecina, M., Karažija, T. and Herak Ćustić, M. (2016). Macrominerals in Red Beet Root under Organic and Mineral Fertilization. Agriculturae Conspectus Scientificus, 81 (3): 173-179.
18. Petek, M. (2009). Mineralni sastav cikle (Beta vulgaris var. conditiva Alef.) pri organskoj i mineralnoj gnojidbi. PhD thesis, Zagreb.
19. Pitura, K. and Michalojc, Z. (2015). Influence of nitrogen doses on the chemical composition and proportions of nutrients in selected vegetable species. Journal of elementology, 20 (3): 667-676.
20. Ryser, J.P. (1982.). Vers l´utilisation pratique du diagnostic foliaire en viticulture et en arboriculture. Revue Suisse Vitic. Arboric. Hortic. 14: 49-54.
21. Škorić, A. (1982): Priručnik za pedološka istraživanja. Fakultet poljoprivrednih znanosti, Zagreb.
22. Tariq, M. and Mott, C.J.B. (2006). Effect of boron supply on the uptake od micronutrients by radish (Raphanus sativus L.). Journal of Agricultural and Biological Science, 1 (2): 1-8.