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RESEARCH ARTICLE

Apple fruit quality, yield and leaf macronutrients content as affected by fertilizer treatment

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Abstract

During two years we have investigated main fruit quality traits, yield and leaf nutrient content at 120 days after full bloom (DAFB) of 'Idared' and 'Melrose' apples on M.9 rootstock when fertilized with complex NPK (15:15:15) alone, and mixture with natural zeolite (Agrozel) and/or cattle manure. Results showed that fruit quality has been strongly affected by cultivars, whereas fertilizer treatments influenced only yield per tree. Moreover, significant impact of cultivar and fertilizer treatment on leaf P, K and Mg was found. Leaf of 'Melrose' contained higher P and K content, and lower Mg content than those of 'Idared'. In 'Melrose', NPK alone increased leaf P, whereas in 'Idared', mixture of NPK+Agrozel and NPK+Manure promoted leaf P, K and Mg content. According to DOP and ΣDOP indexes, excessive leaf Mg content was found, and deficiency of the rest of nutrients. 'Melrose' exhibited better balanced nutritional values for nutrients as compared to 'Idared', whereas NPK+M promoted better balanced nutritional values than other treatments.

Keywords: Macronutrients level, manure, *Malus domestica* Borkh., NPK, zeolite

1. Introduction

Orchard nutrition is a pre-harvest and post-harvest practice that affects productivity and fruit quality and has to be performed very carefully since, after harvest, fruits quality cannot be improved (Crisosto *et al*., 1997). In Serbia, fruit growers primarily use complex NPK fertilizer (15:15:15) and N mineral fertilizers [calcium ammonium nitrate (CAN) and urea], and farmyard manure (Milošević *et al*., 2013). The complex NPK and manure are added to soil in the late autumn and N fertilizers in early spring. In past few decades, natural zeolites with different commercial names, pure or when mixed with N, P, K and organic fertilizers are given in late autumn (Milosevic and Milosevic, 2009). Natural zeolites improve soil electrical conductivity, nutrient retention capacity, and usually increases soil pH (soil conditioner), and among others, are rich source in some nutrients such as N, K, Ca, Mg and micronutrients (Milošević *et al*., 2013). In general, nutritional requirements vary among orchard sites, within the seasons, and can be affected by light, temperature, and available water supply (Bergmann and Neubert, 1976), and also by cultivar, rootstock, cultural practices (Becerril-Román *et al*., 2004; Kucukyumuk and Erdal, 2011) and cultivation methods (Gasparatos *et al*., 2011).

Previous findings showed that primary factor which determined crop nutrient requirements is soil chemical analysis (Bergmann and Neubert, 1976; Ankerman and Large, 1977). However, the results from the orchards and/or field indicated that soil analysis did not provide enough information about the real fruit crop demands for specific nutrients. For this reason, in recent decades the most convenient method to confirm or refute disorders of nutrition and to correct fertilization systems is foliar diagnosis by chemical analysis of leaves, reflecting supply of plant throughout the growing season. Also, leaf analysis is a good way to allow the diagnosis of potential insufficiency or excess, and offers the possibility of determining the nutritional status of crops and correcting deficiencies, if necessary (Montañes *et al*., 1991).

The aim of this study was to explore if fruit quality, yield and mineral content of apple leaf is affected by complex NPK mineral fertilizer alone or mixed with natural zeolite and cattle manure at 120 DAFB on heavy and slightly acidic soil under western Serbian conditions. We assumed that derived data can be used to monitor different fertilization practices and to establishing recommendations for apple orchards fertilization in similar conditions.

2. Materials and Methods

2.1. Experimental layout, plant material and environmental conditions

The study area is situated in the Prislonica villagenear Cacak town (43º53' N, 20º21' E, 310 m a.s.l.), Western Serbia. 'Idared' and 'Melrose' apple cultivars grafted onto M.9 rootstock were used as the plant material in 2011 and 2012. Apple trees were 17~18-years-old, and managed, except irrigation, according to guidance previously reported (Milosevic and Milosevic, 2009). Trial procedure included tree fertilization of each cultivar with: complex mineral NPK (15:15:15) fertilizer alone (0.05 kg m^{-2}) (T_1), mixture NPK (0.05 kg m^{-2}) + natural zeolite (1 kg m^{-2}) commercially named "Agrozel" (T_2) (Milosevic and Milosevic, 2009), NPK (0.05 kg m^{-2}) + cattle manure (5 kg m^{-2}) (T_3), and NPK (0.05 kg m^{-2}) + Agrozel (1 kg m^{-2}) + cattle manure (5 kg m^{-2}) (T_4). All fertilizers were added to soil in late autumn in 2010 and 2011, and distributed using the randomized complete block design with ten trees for each cultivar–fertilizer combination in four replicates.

2.2. Soil and weather conditions

Apple orchard was established on Vertisol or "Smonitza" soil with 1.71% organic mater, 0.15% total N, 73.0 mg kg^{-1} and 280.9 mg kg^{-1}, 0.07% and 4.7 mg kg^{-1} available P_2O_5, K_2O, CaO and MgO, respectively. Soil texture is clay-loamy with a pH 5.20 in 0.01 mol L^{-1} KCl. Hence, soil is rich source in P_2O_5 and K_2O, whereas other macronutrients are in a moderate to low range (Ankerman and Large, 1977).

Data in Table 1 showed that both experimental years were warmer and with highly lower precipitation amounts as compared to long-term average (1965-2010).

2.3. Yield and fruit traits measurements

Yield per tree (kg) of each cultivar-fertilizer treatment was measured on ten trees in four replicates. Sample of 15 fruits in four replicates per each treatment (n = 60) was measured for their weight (FW, g). Flesh firmness (FF, kg/cm^2) and soluble solids content (SSC, °Brix) of all sampled fruits were measured at consumer maturity using penetrometer Bertuzzi FT-327 (Facchini, Alfonsine, Italy) and refractometer Milwaukee MR 200 (Rocky Mount, USA), respectively.

Table 1. Average monthly air temperature and precipitation amount in Cacak for 2011 and 2012

Month	Air temperature (°C)			Precipitation (mm)		
	2011	2012	Normal*	2011	2012	Normal*
April	12.2	12.6	11.5	23.5	70.3	51.6
May	15.5	15.9	16.8	83.2	106.8	72.7
June	20.7	22.3	20.0	64.8	11.8	87.3
July	22.3	25.5	21.5	36.0	45.1	79.1
August	23.4	24.5	21.2	14.7	0.0	58.0
September	21.3	21.0	16.7	32.4	7.8	56.2
October	11.3	14.6	11.4	30.9	54.9	51.1
Mean or total	18.1	19.5	17.0	285.5	296.7	456.0

*Normal refers to the long-term average (1965-2010).

2.4. Leaf mineral analysis

For plant analysis N, P, K, Ca and Mg contents, leaf samples were taken from the middle part of the 1-year-old shoots all around the periphery of the tree at 120 DAFB. About 100 leaves were used per each cultivar-fertilizer combination in both years. Handling and preparation of samples were done in accordance with standard laboratory procedures. Macronutrients were determined with methods and equipments previously described (Milošević *et al*., 2013). Freshly collected leaves were washed with tap-water and then with distilled water within 24 hours of sampling. After air-drying, the samples were oven dried at 70°C to a constant weight, ground by a mini Willey mill (Thomas Scientific Comp., Swedesboro, NJ, USA) and stored in plastic bottles for chemical analysis. Leaf N was determined by Kjeldahl analysis using Gerhardt Vapodest 50s equipment (Königswinter, Germany); P was analyzed spectrophotometrically by the phospho–vanadate colorimetric method (Hewlett Packard 8452A, Ontario, CA); K was determined by flame photometer Flapho 4 (Carl Zeiss, Jena, Germany); and Ca and Mg by atomic absorption spectroscopy (Pye Unicam SP 191, Cambridge, UK). The data are given as % on dry matter for each nutrient. All nutrients were assessed by triplicate per each cultivar-fertilizer treatment, and values are mean ± SE for two years.

2.5. Deviation from optimum percentage (DOP index)

The DOP index is an alternative method to the traditional diagnosis, which is capable of accurately defining the quantity and quality of each nutrient in plants: optimal (DOP = 0), deficiency (DOP < 0) or excess (DOP > 0) (Montañés *et al*., 1991). The DOP index was obtained from leaf chemical analysis by the following formula:

$$DOP = \left(\frac{C_n}{C_o} - 1\right) \times 100$$

where: C_n = foliar content of the tested nutrient, and C_o = critical optimum nutrient content for apple proposed by Bergmann and Neubert (1976). Besides, it provides the general nutritional status of nutrients through the ΣDOP index, and obtained by adding the values of DOP indices irrespective of sign. The lower the ΣDOP, the greater is the intensity of balance among nutrients.

2.6. Data analysis

Data were subjected to analysis of variance (ANOVA) and means were separated by LSD test ($p \leq 0.05$) using the XL-STAT software (Addinsoft, New York, USA).

3. Results and Discussion

3.1. Fruit quality and yield

According to data in Table 2 significant differences between cultivars were observed in FW, FF and SSC. Fruits of 'Melrose' were larger and firmer than 'Idared', and contained lower SSC. The results for FW and SSC are consistent with those of Blažek and Hlušičková (2007) who reported similar tendency for same cultivars, but different for FF level, probably due to the different maturity stage. Yield per tree of both cultivars was similar which also supported by data of previous authors.

The fruit physico-chemical traits of both cultivars were similar under different fertilizer treatments. Indeed, we may suggest that using NPK alone and mixture with Agrozel and/or manure fertilization with the aim of gaining better response on these traits is not justified in apples. On the contrary, fertilization significantly affected yield per tree (Peralta-Antonio *et al*., 2014; Márquez-Quiroz *et al*., 2014). T_1 induced the highest, and T_4 the lowest yield per tree in 'Idared'. However, these fertilizer treatments induced the lowest and statistically the same yields per tree in 'Melrose', whereas the highest yield and with no significant differences between them produced by T_2 and T_3. These data were in accordance with study with Čmelik and Tojnko (2005) who reported that fertilization with different amounts of N had no consistent impact on the 'Idared' cropping. Interestingly, application of T_4 in both cultivars gave poor effect on yield. This result could be explain with the fact that organic N sources, such as manures, are more difficult to manage than the inorganic-N fertilizers, since it is very difficult to predict when their N will become available in the soil, especially in soils with low moisture content (Milošević *et al*., 2013).

Table 2. Fruit quality traits in different fertilizer treatments of 'Idared' and 'Melrose' apple cultivars. Values are the mean ± standard error for 2011 and 2012.

Cultivar	Fertilizer treatment	Fruit weight (g)	Flesh firmness (kg cm^{-2})	Soluble solids content (°Brix)	Yield per tree (kg)
Idared	T_1	190.3 ± 1.9a	6.6 ± 0.5a	12.4 ± 0.6a	25.8 ± 0.6a
	T_2	204.0 ± 15.8a	6.8 ± 0.2a	11.7 ± 0.1a	22.6 ± 0.9c
	T_3	198.5 ± 10.8a	7.0 ± 0.3a	11.7 ± 0.4a	23.7 ± 0.4b
	T_4	213.0 ± 8.6a	6.8 ± 0.4a	11.8 ± 0.3a	21.0 ± 1.0d
Mean		201.5 ± 9.3B	6.8 ± 0.4A	11.9 ± 0.4B	23.3 ± 0.7A
Melrose	T_1	224.5 ± 7.6a	5.8 ± 0.3a	12.6 ± 0.4a	21.0 ± 0.6b
	T_2	247.2 ± 7.7a	5.4 ± 0.2a	12.4 ± 0.1a	24.6 ± 0.3a
	T_3	231.0 ± 9.9a	5.3 ± 0.3a	13.0 ± 0.4a	24.0 ± 0.5a
	T_4	225.0 ± 7.0a	5.1 ± 0.3a	12.3 ± 0.2a	20.9 ± 0.6b
Mean		231.9 ± 8.1A	5.4 ± 0.2B	12.6 ± 0.3A	22.6 ± 0.5A

For T_1–T_4 see section 'materials and methods'; the different small and capital letter(s) in column indicate significant differences among means within each fertilizer and each cultivar, at $p \leq 0.05$ by LSD test, respectively.

3.2. Leaf macronutrients content

Small but significant differences were observed among cultivars for leaf P, K and Mg (Table 3). Differences between them for leaf N and Ca levels were not significant, although 'Idared' belongs to "high N" requirement apple group (Bolohan *et al*., 2011). Moreover, 'Melrose' leaf contain higher amount of P and K, and lower Mg than those of 'Idared'. Several authors found greater variations in levels of nutrients in different apple cultivars, indicating strong genetically controlled traits (Nachtigall and Dechen, 2006; Nagy *et al*., 2006). For instance, Miljković and Vrsaljko (2009) noted that leaf of 'Melrose' had higher N and K, similar P and Mg and lower Ca levels as compared to 'Idared'. Based on the data for K contents, these values are in the "low" K supply category (Nagy and Holb, 2006). It seems that beside others, environment, cultivation system and rootstock play an important role in nutrient status of apple trees (Gasparatos*et al*., 2011; Kucukyumuk and Erdal, 2011).

Except by cultivar, leaf nutrient levels were significantly affected by fertilizer treatments, except for leaf N and Ca (Table 3), indicating that the leaf nutrient composition of the same cultivar can change as the fertilizers treatment changes (Neilsen *et al*., 2004; Becerril-Román *et al*., 2004), however, differences were not consistent. Generally, T_1 increased leaf P in 'Melrose', while T_2 and T_3 promoted leaf P, K and Mg in 'Idared'. These results were expected because Agrozel and manure are rich source in nutrients (Milošević *et al*., 2013). Response of apples to different fertilizer treatments was widely variable (Kucukyumuk and Erdal, 2011).

Table 3. Apple leaf nutrients content in different fertilizer treatments of 'Idared' and 'Melrose' apple cultivars. Values are the mean ± standard error for 2011 and 2012≤≤

Cultivar	Fertilizer treatment	N	P	K	Ca	Mg
Idared	T_1	2.12 ± 0.0a	0.14 ± 0.0b	0.78 ± 0.0bc	1.68 ± 0.2a	0.37 ± 0.0c
	T_2	2.13 ± 0.0a	0.12 ± 0.0c	0.82 ± 0.0b	1.40 ± 0.2a	0.49 ± 0.1a
	T_3	2.25 ± 0.1a	0.17 ± 0.0a	1.00 ± 0.0a	1.31 ± 0.1a	0.34 ± 0.0d
	T_4	2.25 ± 0.1a	0.14 ± 0.0b	0.75 ± 0.1c	1.25 ± 0.1a	0.41 ± 0.0b
Mean		2.19 ± 0.0A	0.14 ± 0.0B	0.84 ± 0.1B	1.40 ± 0.1A	0.41 ± 0.0A
Melrose	T_1	2.24 ± 0.0a	0.19 ± 0.0a	1.17 ± 0.1b	1.19 ± 0.1a	0.35 ± 0.0b
	T_2	2.21 ± 0.1a	0.17 ± 0.0b	1.07 ± 0.1c	1.37 ± 0.1a	0.36 ± 0.0b
	T_3	2.28 ± 0.0a	0.16 ± 0.0b	1.36 ± 0.1a	1.40 ± 0.6a	0.31 ± 0.0c
	T_4	2.26 ± 0.1a	0.13 ± 0.0c	1.03 ± 0.1c	1.22 ± 0.0a	0.41 ± 0.1a
Mean		2.25 ± 0.0A	0.16 ± 0.0A	1.16 ± 0.1A	1.29 ± 0.1A	0.36 ± 0.0B

For T_1–T_4 see section 'materials and methods'; results for N, P, K, Ca and Mg are expressed as % on dry weight basis;the different small and capital letter(s) in column indicate significant differences among means within each fertilizer and each cultivar ($p \leq 0.05$ by LSD test), respectively.

3.3. DOP index

Data in Table 4 showed a relative deviation to the optimum of leaf macronutrient contents in all fertilizer treatments. The $DOP_{N,P,K,Ca}$ was negative and DOP_{Mg} was positive in both cultivars regardless of fertilizer treatments. For DOP_{Ca} level, 'Idared' fertilized with T_1 tended to have a DOP value close to the normal level. Status that leaf Mg is in excessive range, when leaf K is in deficiency has been previously reported, probably a consequence of lower K competition (Nachtigall and Dechen, 2006), which was universally trait of leaf Mg. Deficiency of P is rare in fruit crops but can occur in trees growing on soils low in available P (Beutel *et al*., 1978). The negative DOP_{Ca} can be attributed with its low mobility and low soil content, while negative DOP_K indicated the tendency of K deficiency under all fertilizer treatments although its soil content is high. This may be explained by the decreased K availability in the soil due to its fixation by clay particles (Saykhul *et al*., 2014). Some authors reported that NPK improved leaf N, P and K contents in 'Idared' (Bolohan *et al*., 2011) which is opposite to our data. This state can be explained with absence of irrigation and low precipitation amount during growing cycle in both experimental years (Table 1) because low soil water content and high air temperature limited nutrients availability and their uptake into the root (Neilsen and Neilsen, 2002). Also, under these soil and weather conditions, organic matter decomposition is limited (Becerril-Román *et al*., 2004).

Significant differences were found between cultivars and among fertilizer treatments within same cultivar for nutritional balance or ΣDOP index (Table 4). 'Melrose' exhibited better balanced nutritional values for nutrients as compared to 'Idared'. This result confirms the better adaptation of 'Melrose' to heavy and slightly acidic soil which is associated with its higher tree vigor than 'Idared'. The T_3 promoted the best balanced nutritional values of macronutrients in both cultivars. Unexpectedly, T_2 and T_4 showed the most unbalanced nutrient status in both cultivars probably due to the limited weather conditions.

Table 4.The DOP index and ΣDOP determined from apple leaf macronutrients content at 120 DAFB under different fertilizer treatments of 'Idared' and 'Melrose' cultivars. Values are the mean for 2011 and 2012.

Cultivar	Fertilizer treatment	N	P	K	Ca	Mg	ΣDOP
Idared	T_1	–15	–42	–40	–4	+34	135c
	T_2	–15	–50	–37	–20	+78	200a
	T_3	–10	–29	–23	–25	+24	111d
	T_4	–10	–42	–42	–29	+49	172b
Mean							154A
Melrose	T_1	–10	–21	–10	–32	+27	100c
	T_2	–12	–29	–18	–22	+24	104b
	T_3	–9	–33	+5	–20	+13	79d
	T_4	–10	–46	–21	–30	+49	156a
Mean							110B

For T_1–T_4 see section 'materials and methods'; leaf composition standards for apple based on mid-shoot leaves sampled at 120 DAFB (Bergmann and Neubert, 1976); sign (−) indicates deficiency level, while sign (+) indicates excessive level; the different small and capital letter in latest column indicate significant differences among ΣDOP indexes within each fertilizer and each cultivar($p \leq 0.05$ by LSD test), respectively.

4. Conclusions

Results imply that all fertilizer treatments are inadequate in order to improve fruit quality and prevent the development of N, P, K and Ca deficiency in apples. It seems that fertilization of apples requires a new management practice, including irrigation and liming.

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