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Effect of different rates and methods of application of NPK-fertilizers on the quality of potato tubers

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Abstract: Research on the effect of different rates and methods of application of mineral NPK fertilizers on the quality of potato variety 'Carrera' was conducted on a luvisol of the Radočelo Mountain massif. Treatments included an unfertilized control, NPK 16:16:16 (1500 kg/ha) applied in-furrow at planting, NPK 16:16:16 (1200 kg/ha) applied in-furrow at planting, and NPK 16:16:16 applied at 700 kg/ha during seedbed preparation and at 500 kg/ha in-furrow at planting. Results on the nutritional value of potato tubers showed that the levels of tested nutrients were higher in the skin than in the flesh. The concentrations of tested nutrients in potato tubers were highest at the highest NPK fertilizer rate, whereas the lowest levels of all nutrients, except Fe, were determined in tubers at NPK rates of 700 kg/ha applied pre-plant and 500 kg/ha applied at planting.

Keywords: potato, NPK fertilizers, tuber quality.

Introduction

In order to achieve high, stable and quality yields, the potato plant requires the presence of all macro (N, P, K, Ca, Mg, S) and microelements (Fe, Mn, B, Zn, Cu, Mo), which must be in optimal amounts. The importance of nitrogen primarily lies in the fact that it is a constituent element of proteins, and it

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influences the development of numerous physiological and biochemical processes, plant growth, the formation of organs, and therefore it affects the structure and quality of yield. Phosphorus accelerates tuber growth, increases the quality of tubers (they contain more starch), reduces the scum of tubers. Potassium has an important role in the physiological processes of the plant, improves the quality of cooking and processing, increases the resistance of tubers to injuries and affects the concentration of dry matter. Due to potassium deficiency, it is difficult to keep the tubers, which are then more susceptible to the formation of dark spots. Microelements are included as catalysts in numerous metabolic and physiological processes in plants. Iron is an essential microelement involved in the complex oxidation reaction of ferro-chlorogenic acid during the cooking of potatoes, and the presence of which may cause darkening, which is undesirable; therefore, the optimum amount of this element is necessary in order to avoid this phenomenon. Manganese has a positive effect on the resistance to diseases of potatoes, the synthesis of organic substances, better utilization of the nitrate and ammonium forms of nitrogen. Zinc is a component of many enzymatic systems, and it plays an important role as an ingredient of the hormone auxin. Copper influences the transfer of sugar from the above-ground parts of plants to the tubers, and thus enhances the synthesis and storage of starch in the tubers (Gvozden, 2016).

Excessive amounts of fertilizers can negatively affect not only tuber yield but also tuber quality. Bugarčić (2000) concluded that high rates, above 1500 kg/ha, can negatively affect the productive and technological characteristics of potato tubers. Hajšlova *et al*. (2005) found that the amount of nitrogen used is negatively correlated with the content of dry matter and starch. Also, nitrogen over-fertilization can cause an increase in nitrogen content in tubers relative to potassium content, thus increasing the susceptibility of tubers to after-cooking darkening, as well as a decline in their nutritional value (Rengel and Damon, 2008).

The use of mineral fertilizers, together with other sources of soil contamination, may lead to the occurrence a high concentration of harmful and hazardous substances in the soil. These substances are adopted by plants and included in the plant–human diet chain (Zhuang *et al*., 2009; Bošković-Rakočević *et al*., 2014). In potato tubers, a high content of nitrate nitrogen usually comes from harmful substances (Bošković-Rakočević and Pavlović, 2009). Due to the presence of cadmium in crude phosphates, hazardous materials,, used as raw material for the production of phosphorus fertilizers, can cause an increase in cadmium content in potato tubers (McLaughlin *et al*., 1999; Pavlović *i sar*., 2014). The presence of other heavy metals is mainly due to their high content in the parent material, the atmosphere, irrigation water , exhaust gases, etc. (Al-Khashman, 2004; Wei and Yang, 2010).

Materials and methods

The effect of different rates of mineral fertilizers on the yield and quality of 'Carrera' potatoes was examined in 2015. The experiment was laid out in a randomized block design with three replications at the village of Bzovik, Municipality of Kraljevo (Latitude 43^0 25' 33" N, Longitude 20^0 25' 53" E; 1107 m altitude), on a luvisol of the Radočelo Mountain massif.

The experiment included the following treatments: 1. T1 - Control (without fertilization); 2. NPK 16:16:16 (1500 kg/ha) applied in-furrow at planting, 3. NPK 16:16:16 (1200 kg/ha) applied in-furrow at planting, 4. NPK 16:16:16 applied at 700 kg/ha during seedbed preparation and at 500 kg/ha in-furrow at planting. During seedbed preparation, immediately before planting on 29 April 2015, 700 kg/ha NPK-fertilizers was applied in treatment T4. During planting, on April 30, planned rates of mineral fertilizers were applied to open furrows. Plot size was 23.275 m^2 (4.9 m x 4.75 m).

Before trial establishment, soil samples were collected from a depth of 30 cm for the following analyses: soil pH was measured at a 1:2.5 ratio of soil to distilled water and 1M KCl; humus content was determined by oxidation with $KMnO_4$ solution (according to Kotzman); total nitrogen was estimated by Kjeldahl analysis (Gerhardt Vapodest); available phosphorus and potassium were evaluated by extraction with 0.1M NH_4-lactate and 0.4M CH_3COOH, according to Egner-Riehm (P was analyzed spectrophotometrically by the phospho-vanadate colorimetric method and K was determined by flame photometry); available Al was measured by Sokolov's method. Available Cu, Fe, Zn, Mn, Pb and Ni were determined by extraction with 0.005M DTPA + 0.01M $CaCl_2$ + 0.1M TEA solution, pH=7.3 (Lindsay and Norvell, 1978), and analyzed using atomic absorption spectroscopy.

After harvesting, potato tubers were sampled for determining the nutritional value (levels of major macro- and micronutrients) and the content of some harmful substances in the skin and the flesh. Nitrogen content was determined by elemental analysis using a Vario EL III Elemental Analyzer; the levels of K, Fe, Mn, Cu, Zn, Pb, Ni and Al were assessed by digestion in concentrated HNO_3 and 30% H_2O_2, with K readings made by a flame photometer and measurements of the other elements taken by an ICP.

Results and disscusion

Mean air temperature datafor Kraljevo for the growing season of potatoes in 2015 show that temperatures during potato germination were within the optimal range of values (Table 1). However, in July, especially during the last ten days, the average temperature (25.3^{0}C) exceeded the optimal value (21–25^{0}C), which reduced tuber bulking. According to the results of Bugarčić (2000), temperatures above 25^{0}C significantly reduced tuber bulking.

Table 1. Mean air temperatures (°C) over ten-day periods and months and sum of precipitation (mm) for the area of Kraljevo during the growing season of potatoes in 2015

Months	Temperature (°C)				Sum of precipitation (mm)			
	Ten-day period			Mean	Ten-day period			Total
	I	II	III		I	II	III	
April	7.1	13.5	14.2	11.6	48.2	16.4	2.0	66.6
May	18.2	18.2	16.3	17.6	7.8	35.0	47.7	90.5
June	20.4	21.4	17.8	19.9	17.0	39.2	31.8	88.0
July	23.1	24.2	25.3	24.2	1.2	2.2	5.0	8.4
August	25.2	25.6	22.4	24.4	7.3	27.3	2.1	36.7
September	23.2	19.0	16.3	19.5	15.2	30.8	38.3	84.3

During the growing season in 2015, there was a considerable deficit of rainfall, especially in July and August (Table 1). During germination and potato tuber set, there was enough moisture in the soil, which had a positive effect on potato tuber set. In July, there was only 8.4 mm rainfall precipitation (25 days without precipitation), while in August it was 36.7 mm.

The results of agrochemical testing (Table 2) showed a strongly acid reaction of the soil, and high contents of total nitrogen, available phosphorus and potassium in the soil. The humus content was medium. Regardless of the strongly acid reaction of this soil, mobile aluminum content (3.38 mg/100 g soil) was within the limits tolerable to plants (Jakovljević *et al*., 1991), which is of high importance given the particularly deleterious effect of excess mobile aluminum in the arable layer as evidenced by the decrease in root penetration depth and, hence, reduction in the uptake of nutrients and water from the soil (Foy, 1974).

Table 2. Agrochemical characteristics of the soil

Depth (cm)	pH		Humus (%)	N (%)	P_2O_5	K_2O	Ca	Mg	Al
	H_2O	KCl			mg/100 g				
0–30	4.75	3.80	3.1	0.21	23.26	47.27	128.52	13.27	3.38

The content of available Zn (1.52 mg/kg) was medium, the levels of of DTPA-Fe (55.6 mg/kg) and DTPA-Mn (61.5 mg/kg) were high, while the content of available Cu (0.64 mg/kg) was within the low limits (Ankerman, 1977), (Table 3). The high content of available Fe and Mn was expected, considering the stongly acid reaction of the soil. The content of available forms of Pb and Ni was within the maximum permissible concentration range.

Table 3. Content of available forms of microelements and heavy metals in soil

Depth (cm)	Cu	Fe	Mn	Zn	Pb	Ni
	mg/kg					
0–30	0.64	55.6	61.5	1.52	5.23	1.41

Results on the nutritional value of potato tubers showed that the levels of tested nutrients were higher in the skin than in the flesh (Table 4). The content of nitrogen in the flesh of the tuber was in the range of 1.89% (treatment with NPK 16:16:16 700 kg/ha during seedbed preparation and 500 kg/ha in-furrow during planting) to 2.16% (NPK 16:16: 16 1500 kg/ha applied during planting). In the skin, the content of nitrogen varied from 2.42 to 2.61% in the same treatments. The content of potassium showed a similar tendency of variation in treatments (flesh 2.16–2.34%, skin 3.70–4.02%), as well as nitrogen. The nitrogen content in the flesh was slightly higher than the average values of 1.56% (Bártova *et al*., 2013) and 1.49–1.80% (Rostami *et al*., 2015), whereas the level of K was somewhat lower than the range of 2.6–3.6% (Trehan and Sharma, 2002). These findings were particularly evidenced in treatments with 1500 kg/ha NPK fertilizer, in support of the reports by Rengel and Damon (2008), who found that excessive nitrogen can increase nitrogen content in tubers relative to potassium.

Table 4. Nutritional value of potato tubers

Fertilization treatments		N	K	Cu	Fe	Mn	Zn
		%		mg/kg			
Skin	T2	2.61	4.02	9.04	98.78	87.43	36.88
	T3	2.48	3.70	9.32	117.55	71.58	23.38
	T4	2.42	3.72	6.50	158.07	50.85	25.37
Flesh	T2	2.16	2.34	5.48	28.56	17.03	20.09
	T3	2.00	2.29	5.43	21.82	16.20	16.98
	T4	1.89	2.16	3.26	23.85	10.26	16.00

**T2-1500 kg ha^{-1} applied in-furrow at planting, T3-1200 kg ha^{-1} applied in-furrow at planting and T4 - applied at 700 kg ha^{-1} during seedbed preparation and 500 kg ha^{-1} in-furrow at planting*

Iron is an essential microelement involved in the complex oxidation reaction of ferro-chlorogenic acid during the cooking of potatoes. Deficiency of Fe is the reason underlying after-cooking darkening as an adverse side-effect of heat treatment; therefore, its content in the tuber should be within the average values (21–58 mg/kg, Kabata-Pendias, 2011). In the present experiment, the content of Fe was higher in the skin of the tuber (skin 98.78–158.07 mg/kg; flesh 21.82–28.56 mg/kg), whereas the lowest content was determined in the treatment with 1200 kg/ha of NPK fertilizer applied once, in-furrow at planting. The highest content of Fe was found at the highest application rate of NPK fertilizer.

The results on the content of copper in potato tubers indicated that a higher content of this nutrient was found in the skin (6.50–9.32 mg/kg) compared to the flesh (3.26–5.48 mg/kg). The highest content was obtained in the treatment with 1500 kg/ha of NPK fertilizers applied in-furrow at planting. However, the content of Cu in the flesh was within the average values (3.0–6.6 mg/kg; Kabata-Pendias, 2011) in all treatments.

As with the previously analyzed micronutrients, the content of zinc was within the average values (10–26 mg/kg; Kabata-Pendias, 2011), which is very important in view of the fact that zinc participates in the production of many enzymatic systems (Gvozden, 2016). A higher content of Zn was determined in the skin compared to the flesh (23.38–36.88 mg/kg, 16.00–20.09 mg/kg, respectively).

The content of Mn in the skin of potato tubers ranged from 50.85 to 87.43 mg/kg, while its levels in the flesh were 10.26–17.03 mg/kg, with the highest content in treatment with 1500 kg/ha of NPK fertilizers applied in-furrow at planting.

As already stated, the contents of Cu, Fe, Zn, and Mn in the flesh of the tubers were within the range of average values indicated by Kabata-Pendias (2011), but the contents of these elements were slightly higher than the results obtained by Bártova *et al.* (2013).

In terms of safe food production, it is very important to determine the content of harmful substances, primarily heavy metals in agricultural products, as this is their most common way of entering the plant-human nutrition chain (Zhuang *et al.*, 2009; Bošković-Rakočević *et al.*, 2014). The major problem in growing potatoes on acid soils can be caused by the increased content of aluminum, which significantly reduces yields (Bošković-Rakočević and Bokan, 2003). Also, it can be accumulated in the tubers. The obtained results (Table 5) showed that Al accumulated in the skin of tuber (138.42–295.57 mg/kg), while the content of Al in the flesh was insignificant (4.58–12.89 mg/kg), and was below the average values (76 mg/kg; Kabata-Pendias, 2011).

Table 5. The content of harmful substances in the potato tuber

Fertilization treatments		Al	Pb	Cd	Ni
		mg/kg			
Skin	T2	138.42	0.37	0.27	2.74
	T3	225.35	0.58	0.18	5.34
	T4	295.57	0.61	0.25	4.78
Flesh	T2	4.58	bld	bld	1.38
	T3	5.67	bld	bld	2.47
	T4	12.89	bld	bld	2.68

bld- below the limit of detection

The contents of Pb and Cd in the flesh of the potato tubers were below the limit of detection (Table 5), while the content of Ni (1.38–2.68 mg/kg) was significantly below the toxic concentrations (>10 mg/kg; Kabata-Pendias, 2011). All tested heavy metals were detected in the skin of the tuber, but these values were also low, indicating that potatoes have developed mechanisms at the root that prevent the translocation of heavy metals from the root into edible parts. This mechanism for the sequestration of certain heavy metals (Cd, Cu and Zn) is made possible through sulphur-containing proteins which bind these metals to create metabolically inactive complexes that accumulate in vacuoles within the cells. Thus, these elements are excluded from the translocation process. Characteristically, Mn forms complexes with malate in the cytoplasm through which Mn is transported to the vacuole, where it dissociates from malate and complexes with oxalate as the "terminal acceptor" (Memon *et al*., 2001). In Pb, this mechanism is based on the formation of Pb-lignin complexes in roots (KrishnaRaj *et al*., 2000).

As indicated by the analysis of the effect of different rates and methods of application of NPK fertilizer on tuber quality, the highest levels of all tested nutrients were obtained at the highest rate (1500 kg/ha), as opposed to the lowest levels of all nutrients, except Fe, under NPK treatment at 700 kg/ha applied pre-plant and 500 kg/ha applied at planting, with all values being within the optimal range.

Conclusion

The soil was strongly acid reaction (pH/KCl 3.80), with a high content of total nitrogen (0.21%), available phosphorus (23.26 mg/100g) and potassium (47.27 mg/100g). The humus content was medium (3.10%). The content of available Zn (1.52 mg/kg) was medium, the levels of DTPA-Fe (55.6 mg/kg) and DTPA-Mn (61.5 mg/kg) were high, while the content of available Cu (0.64 mg/kg) was within the low limits. The content of available forms of Pb and Ni was within the maximum permissible concentration range. Results on the nutritional value of potato tubers showed that the levels of tested nutrients were higher in the skin than in the flesh. The highest levels of all tested nutrients were obtained at the highest rate (1500 kg/ha), as opposed to the lowest levels of all nutrients, except Fe, under NPK treatment at 700 kg/ha applied pre-plant and 500 kg/ha applied at planting, with all values being within the optimal range.

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UTICAJ RAZLIČITE DOZE I NAČINA PRIMENE NPK-ĐUBRIVA NA KVALITET KRTOLA KROMPIRA

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Rezime

U cilju ispitivanja uticaja različitih doza i načina primene NPK-đubriva na kvalitet krtola krompira sorte Karera izvedena su ispitivanja tokom vegetacione sezone krompira 2015. godine na zemljištu tipa luvisol, u ataru sela Bzovik (planinski masiv Radočelo, opština Kraljevo). Ogled je postavljen u sledećim varijantama: 1. T1 - Kontrola (neđubreno); 2. T2 - NPK 16:16:16 u količini 1500 kg/ha, primenjeno u brazde za vreme sadnje; 3. T3 - NPK 16:16:16 u količini 1200 kg/ha, primenjeno u brazde za vreme sadnje; 4. T4 - NPK 16:16:16 u količini 700 kg/ha za vreme predsetvene pripreme i 500 kg/ha u brazde za vreme sadnje. Rezultati analiza hranljive vrednosti krtola krompira ukazuju da je sadržaj svih ispitivanih elemenata bio veći u kori u odnosu na srž krtole. Najveći sadržaj svih ispitivanih elemenata utvrđen je primenom najveće doze (1500 kg/ha), dok je najmanji sadržaj hraniva, osim kod Fe, utvrđen primenom NPK-đubriva u količini 700 kg/ha predsetveno i 500 kg/ha u sadnji, pri čemu su sve vrednosti bile u okviru optimalnih količina.

Ključne reči: krompir, NPK đubrivo, kvalitet krtole.