RESPONSE OF ARUGULA (*ERUCA SATIVA* MILL.) TO INORGANIC, ORGANIC AND METALLURGICAL SLAG AMENDMENTS TO ACID SOIL

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Abstract

The aim of this study was to determine an influence of Ca - containing metallurgical slag application, sampled from steel factory area, as well as the influence of commercial lime material and fertilizers, on macro and trace elements content in aerial biomass of arugula, grown on Eutric Cambisol (a soil with high acidity), through greenhouse semi-controlled pot experiments, in 2019. The influence of metallurgical slag was compared to those of commercial lime material ($CaCO_3$) solely and in combination with inorganic and organic fertilizers. Content of N was determined using elemental CNS analyzer, P - by spectrophotometer, and K - by flame emission photometry. In the determination of Fe, Zn, Cu and Cd, ICP-AES was used. Used metallurgical slag, in combination with mineral and organic fertilizer, showed positive effects on the main chemical composition of arugula and its yield. The high and toxic concentrations of trace elements in plant comparing to plants from untreated soil were not significantly increased and were within the permissible levels in plants in all the treatments in spite of their high content in metallurgical slag. The evaluated results obtained in present study showed high potential in usage of the studied alkaline metallurgical slag when it is combined with inorganic and organic fertilizers, to acid soils toward amelioration their fertility without adverse effects.

Introduction

Arugula (*Eruca sativa* Mill.) is an annual herbaceous plant from the Brassiccaeae family. It belongs to the group of leafy vegetables, since the leaf is mainly used for nutrition, has modest heat requirements and is resistant to frost, so it can be produced practically all year round. It is best suited to soils with a neutral reaction, although it can also be grown on soils with an alkaline reaction. However, it is considered that acidic soil condition can significantly affect the reduction of its growth and development [1].

Acidic soils are widespread and limit plant production all over the world [2], with a similar situation in the Republic of Serbia. The productivity of those soils increasingly becoming a limiting factor in plant production. The constant increase in their surface area is the result of intensive production technology, uncontrolled use of inorganic fertilizers, the impact of acid rain, as well as the lack of organic fertilizers usage [3].

In Serbia, Eutric Cambisols [4], used in this reserch, are considered to be mostly medium-heavy soils, with a marked texture difference through the profile. The degree of base saturation is above 50%, where pH in water is around 5.5 [5]. Intensification in use of cambisols, in the manner of inorganic fertilizers overuse, causes their transformation into marginal, often acid soils, with reduced organic matter. Amelioration of these soils (optimum dose of nutrients and their source) play an important role in enhancing the productivity of crops [6]. It is considered that the first step in creating favorable conditions in these soils for productive plant growth is their acidity reduction. The use of traditional commercial alkaline liming materials to acid soils for the amelioration of acidity consequently improving crop production is a common practice [7]. Along with these materials present in Serbia and regarding its alkaline nature, metallurgical slag, sampled from steel factory area, can be of great importance. Although the significant quantities of

metallurgical slag are generated as waste material every day from steel industries, its physicochemical property offers a high potential for its utilization in agriculture. As metallurgical slag contains fertilizer components such as CaO, SiO_2 and MgO, its alkaline property remedies soil acidity. In addition to these three components, it also contains components such as FeO, MnO and P_2O_5, and some slags may contain elevated levels of trace metals such as Fe, Cd, Cr, Cu, Pb, Mo, Ni and Zn, that occur naturally in soil, and many of them are essential plant nutritive. Although there are varying concentrations of trace elements in metallurgical slags, their bioavailability is very low [8]. Metallurgical slag has been used for a broad range of agricultural purposes. On field trials in Pennsylvania the yields of corn, wheat, oats, buckwheat and soybeans with metallurgical slag application were as good or better than an equivalent amount of limestone [9].
The aim of this research was to investigate the effect of Ca-containing metallurgical slag, a by-product from steel factory, on yield and chemical composition (N, P, K, Fe, Zn, Cu, Cd) of the aerial biomass of arugula, grown on Eutric Cambisol (a soil with high acidity) performed in semi-controlled greenhouse conditions. The effect of metallurgical slag were compared to those of commercial lime material ($CaCO_3$) in combination without and with standard inorganic NPK and organic (NPK nutrients of animal origin) fertilizers.

Experimental

The study was performed in Institute of Soil Science in greenhouse semi-controlled vegetative experiments using plastic pots, from the first decade of March to the first decade of May, in 2019. Each pot was filled with 3 kg pot^{-1} of homogenized Eutric Cambisol, brought from an experimental field in Mladenovac town, located about 55 km from Belgrade, Serbia (grid reference: 44°24' N, 20°40' E). In every plastic pot ten arugula seeds were sown. Arugula plants were grown according to the standard growing methods (watering and regular weed control), and without using any plant protection products.
Chemical characteristics of Eutric Cambisol plowed layer, used in present research, were determined in our previous study [10]. Accordingly, the soil is characterized by acid reaction (pH in 1M KCl 4.98), low content of available P (7.98 mg 100 g^{-1}), medium to well supplied with available K (21.8 mg 100 g^{-1}), medium provided with total N (0.28%) and organic matter (3.05%), and very highly provided with available elements: Ca (440 mg 100 g^{-1}), Mg (58 mg 100 g^{-1}), Fe (63 mg kg^{-1}), Mn (43 mg kg^{-1}) and Co (0.26 mg kg^{-1}). According to textural composition, Eutric Cambisol is a clay loam and has a relatively favorable particle size distribution for the plant cultivation.
The following seven designed treatments were carried out in three replications: control - untreated soil (T1); $CaCO_3$ (T2); NPK inorganic fertilizer (NPK) + $CaCO_3$ (T3); NPK organic fertilizer (NC) + $CaCO_3$ (T4); metallurgical slag, MS (T5); NPK + MS (T6); NC + MS (T7). Before sewing the arugula, the amount of fertilizers, $CaCO_3$ and slag was measured according to the experimental design and mixed with soil (calculated as for 1 ha): NPK inorganic fertilizer (15:15:15) = 500 kg ha^{-1}; NC organic fertilizer = 170 kg ha^{-1}; $CaCO_3$ = 4 t ha^{-1}; MS = 4 t ha^{-1} (same as the amount of $CaCO_3$). Both MS and $CaCO_3$ with granulation of 0.2 mm were used in the experiment.
The samples of metallurgical slag used in present study were taken during spring 2009 from different deposition sites of Steel factory – Smederevo, Serbia (previously US Steel, now Hesteel Smederevo Steel Plant) located approximately 60 km South-East from Belgrade.
Chemical composition of used MS was determined in our previous study [3]. Accordingly, this material has very alkaline reaction (pH in H_2O 12.48), with the content of calcium in oxide forms (CaO) from 33-45%, of which about 50% is easily soluble in 1 M ammonium acetate; content of the total Mg was mainly in forms of MgO, while nearly all the amount of P is in available forms for plants; contents of the total Fe (15.34 %) and Mn (1.80 %) are high, but with lower amounts

of their soluble forms; content of the total Zn is in lower amounts (14.60 %), while the total content of Cu is a little higher (228.80 %).

Organic fertilizer applied in present research is a solid NPK 4:3:4 nutrient of animal origin, commercially called Nervosol Complex (NC). According to its main chemical composition, it consists of 4% of total N, 4% of organic N, 3% of P (P_2O_5 form), 4% of K (K_2O form), and 30% of organic C [11].

The aerial biomass (stems with developed leaves) of arugula plants was taken at the beginning of rosette formation from each experimental variant and replicate in experimental pots. Biomass was then air-dried and the yield of plants was measured and expressed in g pot^{-1}, after which it was dried for 2 hours at 105°C and weighed again for chemical analyses, using gravimetric method for determination of dry matter content of plant tissue [12]. The content of total N was determined on elemental CNS analyzer Vario EL III [13]. The content of P was determined by spectrophotometer with molybdate, and the content of K - by flame emission photometry [14]. The content of trace elements - Fe, Zn and Cu, as well as the toxic heavy metal Cd, was determined using inductively coupled plasma-atomic emission spectrometry (ICP-AES), after microwave oven extraction and moisture content [15].

The effects of experimental treatments on the studied chemical parameters and yield of the plants were evaluated using the SPSS ANOVA, followed by Duncan's Multiple Range Test (DMRT). Significant differences between means were tested by the LSD test at P = 0.05.

Results and discussion

Plant analysis can play a major role when diagnosing mineral nutrition and trace elements problems, whether for research purposes, or for solving practical field problems for farmers and growers. The concentrations of all analyzed macroelements (Table 1) and trace elements (Table 2) in arugula aerial biomass were *significantly affected* by all treatments applied (T1-T7).

Table 1. Macroelements content in arugula and its yield depending on the treatment used

Treatments	Macroelements (% in dry biomass)*			Yield* (g pot^{-1})
	N	P	K	
T1 - control (untreated soil)	3.10±0.01^{d}	0.64±0.02^{b}	2.89±0.03^{e}	6.31±0.51^{b}
T2 - $CaCO_3$	3.31±0.31^{a}	0.81±0.03^{b}	3.83±0.11^{bc}	6.44±0.12^{b}
T3 - NPK + $CaCO_3$	4.28±0.19^{b}	0.84±0.02^{b}	3.86±0.27^{b}	6.69±1.62^{b}
T4 - NC + $CaCO_3$	4.52±0.13^{b}	0.69±0.01^{b}	3.35±0.26^{d}	6.52±0.70^{b}
T5 - MS	3.81±0.15^{c}	0.70±0.02^{b}	3.41±0.17^{d}	6.52±1.32^{b}
T6 - NPK + MS	5.13±0.17^{a}	2.76±0.22^{a}	5.85±0.13^{a}	7.89±1.79^{a}
T7 - NC + MS	4.86±0.09^{a}	0.92±0.07^{b}	3.93±0.19^{c}	7.93±5.33^{a}
P value	***	***	***	***
LSD (0.05)	0.239	0.377	0.329	0.272

*means ± standard deviation; LSD - least significant difference; *, **, *** - statistical significant differences at P<0.05, P<0.01 and P<0.001, respectively; values followed by the same letter in a column are not significantly different at P<0.05.

Results of the main macroelements content (N, P, K) in arugula aerial parts show high statistically significant differences (*P****) between the treatments at P<0.05 for all studied elements, particularly for P and K (Table 1). Regarding to that, there is a noticeably tendency of an increase in the content of N, P and K in tested plant material in the treatments that included NPK inorganic and NC organic fertilizer, respectively, in combination with MS (T6 and T7), in relation to other treatments including control. The results of arugula yield were in accordance with chemical ones, meaning that the yield was highly significantly higher (*P****) at P<0.05 in treatments T6 and T7 (Table 1). The promotion of arugula biomass growth which led to the promotion of its yield could be explained by improved organic and inorganic nutrition mixing with metallurgical slag. According to Prasad and Power [16], the optimum pH range in soil for growth of most crops is between 5.5 and 7.0, within which most plant nutritives are available. Most plant nutrients will not dissolve when the soil is either too acidic or too alkaline. Depending upon individual needs of vegetables, such as availability to plant roots, the pH level determines what nutrient elements, such as N, P, and K, become available to plants and how efficiently they are absorbed when they dissolve in water or soil moisture. Crops, including arugula, grown on acid soil low in organic matter are likely to be injured more by acidity than on soil having the same acidity but higher in organic matter content [17, 18]. However, application of organic and inorganic fertilizers in combination with lime, such as metallurgical slag, proves to be an excellent package for improving productivity and health of acid soils.

The concentration of trace elements in arugula aerial parts shows that there are statistically highly significant differences (*P****) between different treatments at $P<0.05$ for all studied trace elements (Table 2). The content of Fe, Zn and Cu in plants from all treatments were in the range of normal and critical concentrations, but far below the toxic values [19, 20, 21]. Zn can become toxic since its activity increases rapidly with decreasing pH, and at pH above 7.0 its bioavailability to crops is substantially reduced [22]. There were not found toxic levels of Cu and Fe in aerial plant parts in the treatments where solely metallurgical slag was applied in spite of their significant content in this liming material. According to the reference values [19, 20, 21], the content of Cd was within the safety limits and permissible levels in all the treatments, which is a highly desirable outcome since Cd is a highly mobile element and can be easily translocated to the aerial plant parts, causing a toxicity [23].

Table 2. Effect of applied treatments on the content of trace elements in arugula biomass

Treatments	Trace elements (% of dry biomass)*			
	Fe	Zn	Cu	Cd
T1 - control (untreated soil)	100.35 ± 1.07^{c}	48.58 ± 2.02^{de}	6.88 ± 0.13^{d}	0.64 ± 0.05^{b}
T2 - $CaCO_3$	263.34 ± 7.82	60.22 ± 8.63^{c}	7.67 ± 0.45^{c}	0.42 ± 0.02^{e}
T3 - NPK + $CaCO_3$	57.34 ± 4.11^{d}	63.56 ± 3.70^{abc}	8.30 ± 0.26^{abc}	0.53 ± 0.03^{c}
T4 - NC + $CaCO_3$	49.33 ± 2.55^{d}	46.68 ± 1.81^{e}	8.25 ± 0.15^{abc}	0.45 ± 0.01^{d}
T5 - MS	123.66 ± 3.49^{b}	69.77 ± 3.03^{a}	8.45 ± 0.08^{a}	0.63 ± 0.09^{b}
T6 - NPK + MS	26.67 ± 6.43^{e}	60.93 ± 4.64^{bc}	8.24 ± 0.12^{abc}	0.76 ± 0.02^{a}
T7 - NC + MS	28.32 ± 6.51^{e}	56.43 ± 4.91^{cd}	8.33 ± 0.23^{ab}	0.52 ± 0.01^{c}
P value	***	***	***	***
LSD (0.05)	14.862	6.909	0.577	0.059
Reference value (MPL)				
Normal	50[1]	15[3]	3[3]	<0.1-1[3]
Critical	250[1]	150[2]	15[2]	5[2]
Toxic	600[2]	200[2]	20[2]	10[2]

*means ± standard deviation; LSD - least significant difference; *, **, *** - statistical significant differences at $P<0.05$, $P<0.01$ and $P<0.001$, respectively; values followed by the same letter in a column are not significantly different at $P<0.05$; MPL - maximum permissible levels; literature source: [1][19], [2][20], [3][21].

Conclusion

The results of the paper indicate that the treatments with combination of metallurgical slag and organic and mineral fertilizer, respectively, showed positive effects on the content of main and beneficial biogenic macroelements in aerial parts of arugula, particularly in relation to control. Such improved nutrition would explain the promotion of arugula biomass growth which led to the promotion of its yield (the results on arugula yield were in accordance with chemical ones). The contents of trace elements in plant, including toxic Cd, comparing to untreated soil, were not significantly increased and were within the permissible levels in plants in all the treatments. Consequently, high potential has been estimated in the application of the studied alkaline metallurgical slag, particularly, when combined with mineral and organic fertilizers, to acid soils toward amelioration their fertility without adverse effects.

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