RESEARCH ON THE INFLUENCE OF SLAG FROM THE STEEL INDUSTRY ON MAIZE CULTIVATION

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Abstract

The recovery of by-products from the steel industry, such as steel slag, in agricultural activities, has become increasingly important, as it contributes to reducing the accumulation of this waste in the surrounding environment, to increasing the production of agricultural crops, and it also contributes, due to its chemical properties, by increasing the pH values and the concentration of macroelements and microelements found in soil and in crop plants. The main chemical components contained in this waste, that are important for their use in agriculture, are CaO, MgO, SiO_2, FeO and MnO. The quantity of these components, in each type of slag, varies greatly depending on the raw materials used, the type of steel manufactured, the processing unit and other aspects. The research followed up on the effects resulted from the use of two types of steel slag that were applied in different doses (1 t/ha, 3t/ha and 5 t/ha) and of two calcareous amendments and their influence on the quality and quantity of maize cultivated in the experimental field at Moara Domnescă. The results showed an increase in maize production, an increase in biomass and also an increase in the concentration of macroelements and microelements found in maize grains.

Key words: liming materials, slags furnal, heavy metals, soil

The metallurgical industry can produce various residues, some of which can be used successfully in the agricultural activity, such as steel slag, which has brought important benefits in agriculture and can be used as fertilizer or to correct soil acidity (Das A. *et al*, 2007).

The main chemical components, that slags contain in their composition and which are important for their use in agriculture, are CaO, MgO, SiO_2, P_2O_5, FeO, and MnO. The amount of these components varies widely in each type of slag, depending on raw materials, type of steel made, furnace conditions, and other aspects (Yi H. *et al*, 2012; Shi C., 2004**).**

Slag application favors the increase of pH and the availability of nutrients such as Ca, Mg, and Si in the soil, which leads to the increase in the absorption of these elements by the plant, favoring the growth and yield of the crops. Slags application may supply silicon, which is considered a beneficial element to plants. Silicon may bring benefits to plants, such as reduction of foliar diseases, improvement in pest control, increase in photosynthetic capacity due to the silicon benefit to the architectural activity of the plant, leaving the leaves more upright (Corrêa J.C. *et al*, 2008), and improvement in the use of water by the plant (Daren C.W. *et al*, 1994). It may also influence the uptake and translocation of various macro and micronutrients and can increase plant tolerance to excess of Mn and Fe (Tavakkoli E. *et al*, 2011) and Zn, Al, and Cd (Liang Y. *et al*, 2007).

The influence of slag fertilizer on the soil microbiome ia diverse /varied and the possible mechanisms of slag-microbes interactions can be as following: (1) slag fertilizer supplies nutrients not only to the plant but also to soil microorganisms; (2) slag fertilizer modifies soil microbial habitats by improving the soil's properties (e.g., increasing soil pH) (Gwon H.S. *et al,* 2018), which is essential for nutrient mobilization and microbial growth; (3) silicate fertilizer increases plant photosynthesis (Detmann K.C. *et al*, 2012) and likely increases belowground carbon allocation through root exudates, which eventually triggers soil microbial proliferation and activities; and (4) steel slag enhances heavy metal immobilization in soil (Ning D. *et al*, 2016) and thus, reduces their bioavailability and toxicity to microbes.

MATERIAL AND METHOD

The research was carried out at the Moara Domnescă Didactic Station/Farm, where two experiments were organized in 2020, in order to follow up on the influence of the application on the

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soil of two types of slag from the steel industry, their influence on the physico-chemical properties of reddish preluvosoil and also on the maize culture.

The two types of steel slag used in these experiments are furnace slag (LF) and converter slag (CV), both are a by-product of the steel industry and came from the ArcelorMittal Galați.

Table 1

Chemical and physical characterization of different slags. (ArcelorMittal Galați)

Materials	Fe (%)	SiO_2(%)	CaO (%)	MnO (%)	MgO (%)	Al_2O_3 (%)	P_2O_5 (%)
Furnace slag (LF)	0.98	11.89	52.56	0.56	4.15	22.28	0.29
Converter slag (CV)	11.68	17.87	48.76	5.23	2.98	2.91	2.26

In order to make a comparison, in regards to the influence of these slags on the physico-chemical properties of the soil and also on the maize crops, amendments commonly used in agricultural practice - calcium carbonate and dolomite, were also used in order to correct the acidic pH reaction of the soil.

Table 2

Chemical composition of the slags used in the experiment

Materials	Na (%)	Ca (%)	Mg (%)	Cd mg/kg	Cr mg/kg	Cu mg/kg	Ni mg/kg	Mn mg/kg	Pb mg/kg	Zn mg/kg	Fe (%)
LF slag	0.28	11.7	5.43	nd*	7.61	2.39	4.88	9084	0.3	6.3	0.08
CV slag	0.023	18.5	1.62	nd*	7.25	20.1	3.68	28164	3.75	40.8	12.2
Maximum allowable limit for soil – Order 344/2004				3	100	100	50	-	50	300	-

**nd – not detectable*

The experiment was performed in accordance with the adopted scheme, corresponding to a single-factor experiment, respecting the methodology of randomized blocks, with 6 experimental variants for each experiment, in 3 repetitions, and the surface of an experimental variant being equal to 24 m² (6x4).

RESULTS AND DISCUSSIONS

In the first experiment, where blast furnace slag (LF) was used, 6 experimental variants in 3 repetitions were organized: V1: untreated/control, V2: $CaCO_3$ -2 tons/ha, V3: $CaMg(CO_3)_2$ - 2 tons/ha, V4: LF slag - 1 t/ha, V5: LF slag -3 tons/ha, V6: LF slag - 5 tons/ha.

The second experiment, with converter slag (CV), also included 6 experimental variants in 3 repetitions: V1: untreated control, V2: $CaCO_3$-2 tons/ha, V3: $CaMg(CO)_2$ - 2 tons/ha, V4: CV slag - 1 tons/ha, V5: CV slag - 3 tons/ha, V6: CV slag - 5 tons/ha.

The application of slag and calcareous amendments was made on 19th March 2020 and they were incorporated in the soil.

The application of calcareous amendments on agricultural soils provides the best results if the material can be incorporated in the first 15 cm of soil. This depth represents most of the rooting environment, from where the plant takes its nutrients and water. Incorporation is also very important for slag, so as to ensure maximum mixing with the soil. In some cases, in hay crops or orchards, incorporation may not be feasible. In this case, calcium hydroxide, $Ca(OH)_2$, can be leached from the surface on the soil profile, and most of the pH increase will be in the first 5 cm (Ito.K, 2015).

Influence on the soil's properties

The reddish preluvosoil from Moara Domnească shows the soil reaction in the surface horizon of 5.27, the humus content of 2.46%, Nt of 0.105%, P_{AL} 59%, K_{AL} 105% and the C/N ratio of 12.4. The degree of saturation in bases is 72%, the hydrolytic acidity is 5.89 and the sum of the exchange bases is 15.18 (Mihalache M., 2016).

Table 3

The main chemical properties of the reddish preluvosoil from Moara Domnească

Soil horizon	Humus (%)	pH		N total (%)	
	Values	Values	Assessment	Values	Assessment
Ap	2.46	5.27	Moderately acidic	0.105	Low
Ao	2.05	5.96	Weakly acidic	0.082	Very low
A/B	1.5	6.5	Weakly acidic	0.074	Very low
Bt_1	1.4	6.7	Weakly acidic	0.062	Very low
Bt_2	1.2	6.9	Neutral	0.060	Very low
C	0.7	6.7	Weakly acidic	-	-

Following the application of the steel slag, the nitrogen content of the maize grains was of 1.3% for the control variant and 1.47% for the LF slag variant after applying 5tonnes/ha, as seen in (*figure 1).*

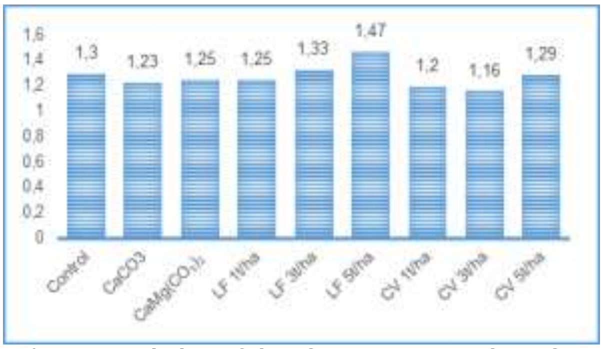

Figure 1 **Variation of the nitrogen content in maize grains, depending on applied doses (%)**

The phosphorus found in maize grains increased slightly with the applied dose, from 0.12% for the control variant, to 0.14% after the application of 3 tonnes of LF slag per hectare, as shown in (*figure 2).*

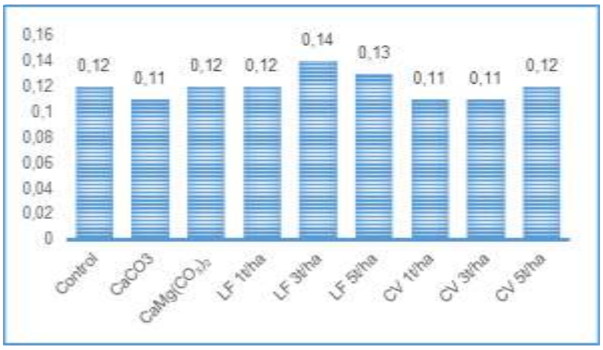

Figure 2 **Variation of the phosphorus content in maize grains, depending on applied doses (%)**

The calcium content of the corn grains registered the highest value at the variant where the dose of 5 tons of LF slag per hectare, 0.023%, compared to the untreated variant where the value was 0.015% (*figure 3*).

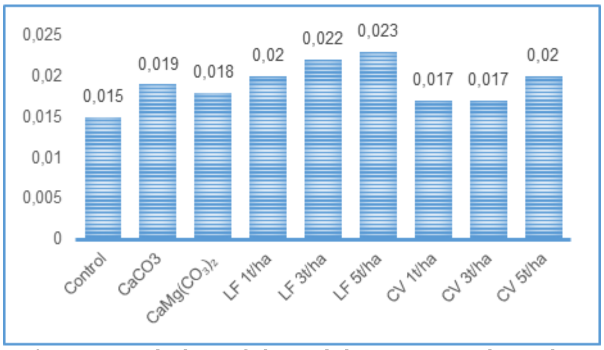

Figure 3 **Variation of the calcium content in maize grains, depending on applied doses (%)**

Potassium in corn grains registered the highest value when applying the dose of 3 tons of CV slag per hectare, 0.53%, compared to the untreated variant with a value of 0.32% (*figure 4*).

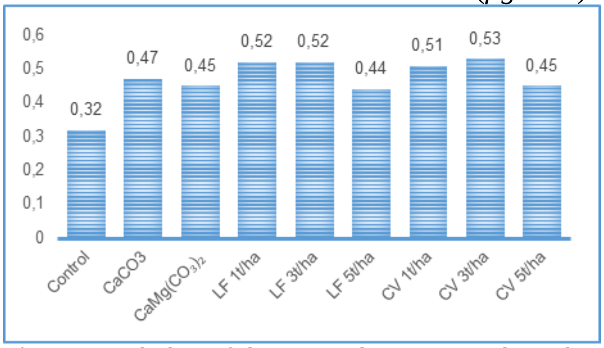

Figure 4 **Variation of the potassium content in maize grains, depending on applied doses (%)**

According to Bressani, Breuner and Ortiz, 1989, the mineral content of maize grains (g/100gr) is: Ca – 48.3±12.3; Mg – 107.9±9.4; P – 299.6±57.8; K – 324.8±33.9.

Influence on plant height

Regarding the influence of slag on the height of maize plants, significant impact can be observed in all experimental variants, as shown in (*figure 5)* and in *(figure 6).*

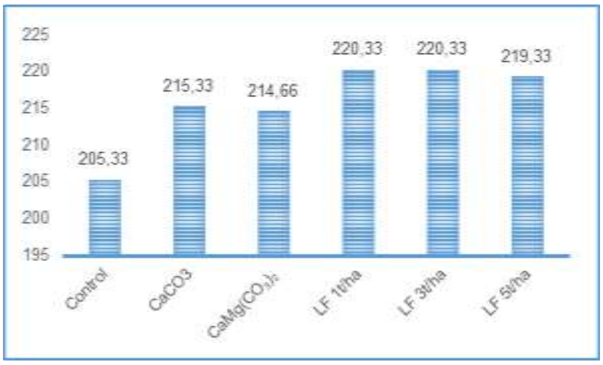

Figure 5 **Influence of the application of furnace slag (LF) on the height of maize plants (average -cm)**

In the experiment where blast furnace slag (LF) was applied, the height of the maize plants was of 220.33 cm for the variants with 1 tonne and 3 tonnes of slag per hectare, compared to the control variant where the average height of the plants was of 205.33 cm.

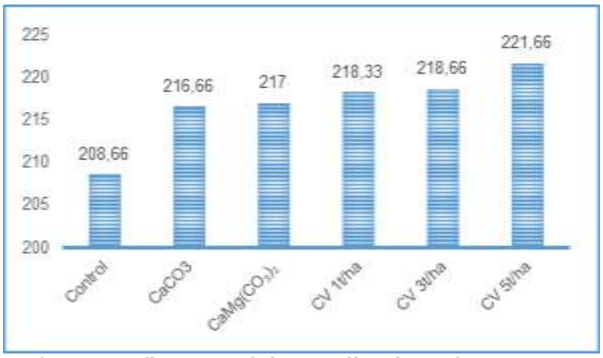

Figure 6 **Influence of the application of converter slag (CV) on the height of maize plants (average - cm)**

In the experiment where converter slag (CV) was applied, the height of the plants increased proportionally with the applied slag dose, reaching a height of 221.66 cm in the variant with 5 tonnes of CV slag per hectare, compared to the control variant, where the average height was of 208.66 cm.

Influence on maize production

The highest values for maize production, in the conditions of the year of 2020, and after the application of blast furnace slag, were registered in two variants, respectively after applying the dose of 3 tonnes/ha, with the production being of 8724.33 kg/ha and after a dose of 5 tonnes/ha, with a production of 7059.33 kg/ha.

High productions, significant, distinctly significant and very significant productions / yields were also obtained in the case of applying converter slag, the highest production being in the V6 variant where 5 tonnes/ha were applied, resulting in a production of 7541.33 kg/ha, compared to the control varian,t where the production of maize was of 6103.66 kg/ha.

Table 4

The influence of LF slag on maize production

Variant	Production		Difference		Significance
	kg/ha	%	kg/ha	%	
V1=Control	6133.33	100	Mt	-	
V2=$CaCO_3$ 2t/ha	6900	112.5	0.76	12.5	
V3=$CaMg(CO_3)_2$ 2t/ha	6802	110.90	0.66	10.90	
V4=LF 1t/ha	6630.66	108.10	0.49	8.10	
V5=LF 3t/ha	8724.33	142.24	2.59	42.24	***
V6=LF 5t/ha	7059.33	115.09	0.92	15.09	*
LSD 5%=0.899 *LSD 1%=1.279* *LSD 0.1%=1.852*					

Table 5

The influence of CV slag on maize production

Variant	Production		Difference		Significance
	kg/ha	%	kg/ha	%	
V1=Control	6103.66	100	Mt	-	
V2=$CaCO_3$ 2t/ha	6901	113.06	0.79	13.06	*
V3=$CaMg(CO_3)_2$ 2t/ha	6831	111.91	0.72	11.91	*
V4=CV 1t/ha	6827	111.85	0.72	11.85	*
V5=CV 3t/ha	7135.66	116.90	1.03	16.90	**
V6=CV 5t/ha	7541.33	123.55	1.43	23.55	***
LSD 5%=0.644 *LSD 1%=0.916* *LSD 0.1%=1.325*					

Influence on heavy metal content in maize grains

The content of heavy metals (Cu, Zn, Pb, Ni, Cr, Co) in maize grains is below the maximum permissible limits. No increase in heavy metals content was recorded with the increase of the applyed slag dosage.

The lead content of maize grains varied between 0.3-1.0 mg/kg, the Cu content varied between 0.1-0.7 mg/kg and the Zn content between 16.8-27.5 m /kg. Cr and Co recorded values below the detection limit.

Table 6

The heavy metal content in maize grains from the experimental variants

No.	Identification	Tests performed							
		Zn	Cu	Mn	Fe	Cr	Co	Pb	Ni
		g/kg							
1	Control	20.0	bdl*	2.3	11.1	bdl	bdl	0.9	1.6
2	$CaCO_3$	19.9	0.1	2.2	12.7	bdl	bdl	0.7	1.1
3	$CaMg(CO_3)_2$	22.3	bdl	1.8	11.8	bdl	bdl	0.7	1.1
4	LF 1t/ha	21.6	0.1	1.5	9.8	bdl	bdl	0.8	2.9
5	LF 3t/ha	27.5	0.7	2.6	56.4	bdl	bdl	0.6	2.7
6	LF 5t/ha	21.7	0.5	2.4	28.3	bdl	bdl	0.4	3.6
7	CV 1t/ha	23.2	bdl	2.3	14.2	bdl	bdl	0.3	2.4
8	CV 3t/ha	17.7	bdl	1.8	7.3	bdl	bdl	0.7	1.2
9	CV 5t/ha	16.8	bdl	1.9	9.2	bdl	bdl	1.0	2.8

**bdl – Bellow detection limit*

CONCLUSIONS

- The application of slag on agricultural lands leads to the increase of the soil's pH reaction, to the increase of organic matter content in the soil and to a better capitalization of the nutrients by the crop plants;
- The application of residues from the metallurgical industry positively influenced the maize production;
- The highest corn production was obtained for the variant where 3t/ha of furnace slag (LF) was applyed, where the obtained production was of 8724,33 kg/ha.
- In addition to calcium intake, slag from the steel industry also brings a supply of microelements.
- In the context of applying the slag from the steel industry, the calcium content the corn grains registered the highest value at the variant where the dose of 5 tons of LF slag per hectare, 0.023%, compared to the untreated variant where the value was 0.015%.
- In the experiment where converter slag (CV) was applied, the height of the plants increased proportionally with the applied slag dose, reaching a height of 221.66 cm in the variant with 5 tonnes of CV slag per hectare, compared to the control variant, where the average height was of 208.66 cm.
- By applying steel slag, no accumulation of heavy metals was found in the soil, even at the maximum application doses, which does not constitute a restriction in the use of this amendment.
- In the maize grains, following the analyzes performed, no accumulation of heavy metals was found.
- These residues from the metallurgical industry can be recovered with good results in agriculture and positively influenced the production of maize.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the University of Agronomic Sciences and Veterinary Medicine of Bucharest- the "Belciugatele" research station, "Moara Domnească" development farm and the ArcelorMittal Galati Siderurgic.

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