Scientific Papers. Series A. Agronomy, Vol. LXVII, No. 1, 2024
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

THE USE OF SECONDARY PRODUCTS FROM THE STEEL INDUSTRY ON AGRICULTURAL CROPS

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Abstract

In a global economic system conditioned by limited resources and faced with increasing worldwide demand as well as increasing environmental degradation, the only viable option remains the resource-efficient, circular economy. Our planet has limited quantities of essential resources such as water and soil. This paper provides information on research carried out using steel slag as a soil amendment and its influence on agricultural crops. The use of steel slag on chromic luvisols from the didactic farm Moara Domneasca has been successfully used as an amendment to correct soil reaction as an alternative to the currently used acid soil correction materials (limestone and dolomite). On the other hand, since slag contains essential plant nutrients such as P, Mn, Fe, Ca, etc. in different concentrations, its application has positively influenced crops production. This use allows reducing the consumption of natural resources and provides a great agricultural, environmental and economic gain by minimizing the negative environmental effects of steel slag.

Key words*: steel slag, soil amendment, mineral ferilizer, sustainability and green remediation materials.*

INTRODUCTION

Using steel slag to improve acid soils and improve nutrient availability for plants is a cost-effective approach and an environmentally friendly alternative that helps reduce problems related to waste. Therefore, the use of slag from the steel industry as a limestone amendment and/or mineral fertilizer is of great importance (Hemalatha, 2013; Wen et al., 2020).

Slag results from the steelmaking process and can be successfully used as an amendment to correct soil reaction as an alternative to natural materials (limestone and dolomite) (Daoud et al., 2013; Deus et al., 2018; Mamatha et al., 2018; Petcu (Vasile) et Mihalache, 2021).

On the other hand, since steel slag contains essential nutrients for plants, such as P, S, Mn, Fe, Mo, etc., in different concentrations, it contributes to soil fertility as a mineral fertilizer. Due to the calcium silicate content it can be used as an important source of nutrients for silicon-sensitive plants and for improving disease resistance (Ito, 2015; Yang et al., 2018; Das et al., 2019; O´Conner et al., 2021).

There are many successful studies and applications in different parts of the world that explicitly demonstrate that steel slag can be effectively used to remediate acidic soils and is an economic amendment (Islam et al., 2022; Radic et al., 2013; Mamatha et al., 2018).

Steel slag contributes to soil fertility and thus crop yield, as it contains an amount and variety of essential plant nutrients. It can be used directly as a fertilizer or it can be used to prepare compost with plant and animal waste (Reuter et al., 2004; Winkler, 2011; Manso et al., 2013).

MATERIALS AND METHODS

The research was carried out in the period 2020-2023 in the experimental field of the Faculty of Agriculture from SDCDA Moara Domnească located in the south-eastern part of Romania, 25 km from Bucharest. In the framework of the conducted research, the influence of the application of two types of slag from the steel industry on the physico-chemical properties of the reddish preluvosol, but also on the crop plants, was followed.

To make a comparison on the influence of slag on the physicochemical properties of the soil, but also on the crops, were used and amendments currently used in agricultural practice to correct the acid reaction of the soil.

In the experience, the 9 variants were represented as follows: V1 - untreated control;

V2 - 2 tons/ha $CaCO_3$, V3 - 2 tons/ha $CaMg(CO_3)_2$, V4 - blast furnace slag (LF) - 1 ton/ha, V5 - blast furnace slag (LF) - 3t/ha, V6 - blast furnace slag (LF)-5t/ha, V7 - converter slag (CV) - 1 ton/ha, V8 - converter slag (CV) - 3 tons/ha, V9 - converter slag - (CV) - 5 tons/ha.

The steel slag used in this study can represent a source of certain nutrients beneficial to both soil and plants, as a by-product of the steel industry and it came from the ArcelorMittal Galati.

In the experimental field, the following measurements and determinations were made: the height of the corn plants, the production of cobs and the production of grains. The results obtained were processed statistically and interpreted through the analysis of the limit differences.

RESULTS AND DISCUSSIONS

The soil on which the experimental field was located is a reddish preluvosol, characterized by the presence of a high percentage of clay that varies from 32.4% in the upper horizon 0-20 cm, 33.4% at a depth of 20-40 cm and 39, 4% at depths greater than 40 cm, which leads to a loamy-clay texture.

The reddish Preluvosol from Moara Domneasca shows a pH in the surface horizon 5.27, humus content 2.46%, Nt 0.105%, PAL 59 mg/kg, KAL 105 mg/kg and the C/N ratio 12.4 (Mihalache et al., 2016).

Regarding the influence of the application of the treatments on the height of the corn plants in 2020, differences can be observed between the experimental variants, the highest value was recorded in the variant on which converter slag was applied in a dose of 5t/ha (an average of 221.66 cm) compared to the control variant where the average was 205.33 cm. In the experimental variants on which the blast furnace slag was applied, the height of the plants reached a maximum of 220.33 cm in the variants with 1t/ha and 3t/ha respectively. Also, in all the variants on which slag was applied, the height of the plants was higher than in the untreated variant (Figure 1).

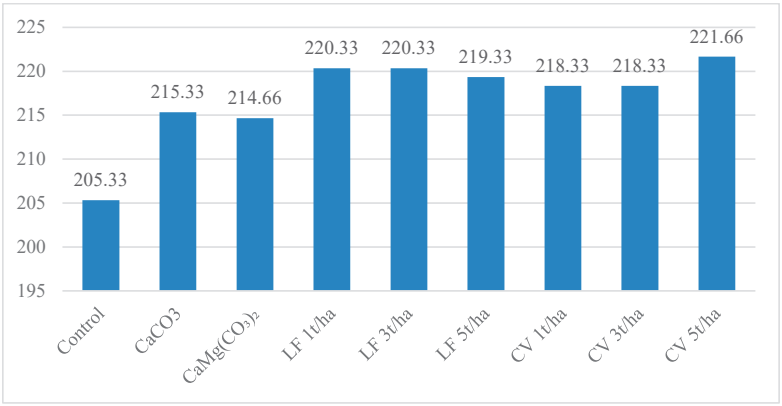

Figure 1. The influence of the application of treatments on the height of corn plants (year 2020)

In 2023, the height of the maize plants at harvest recorded average values between 192-212.66 cm, lower than in 2020, this fact also due to the very low precipitation in 2023, 422 mm, compared to 568 mm in 2020.

However, there were significant differences between the experimental variants. The highest average height was also recorded in the version on which 5t/ha CV slag was applied, 212.66 cm compared to 192 cm in the control variant. And in the variants on which the LF slag fertilizer was applied, the plants were taller than the control variant, the highest being in the variant on which 3t/ha were applied, 212.33 cm (Figure 2).

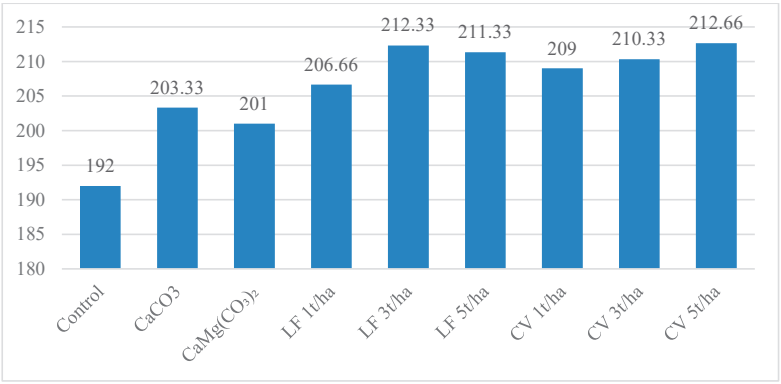

Figure 2. The influence of the application of treatments on the height of corn plants (year 2023)

Regarding the influence of the amendments on the weight of corn cobs in 2020, the highest value was recorded in the version where 3 t/ha of LF slag was applied, respectively 9.81 t/ha, compared to the control variant with 7.44 t/ha.

In the experimental variant on which the maximum dose of CV slag (5 t/ha) was applied, the increase compared to the control variant was significant, respectively 1.34 t/ha.

In the variants where the minimum dose of slag was applied (1 t/ha), the differences compared to the control variant are not significant (7.6 t/ha compared to 7.4 t/ha) and are smaller than in the variants where calcium carbonate (7.96 t/ha) and dolomite (7.71 t/ha).

At the dose of 5 t/ha LF slag, the maximum dose, the production of cobs was 8.2 t/ha, about 1t more than the untreated variant, and at the variant on which CV slag was applied at a dose of 3 t/ha, the cobs production was 8.19 t/ha (Table.1).

Table 1. The influence of the application of treatments on the production of cobs (year 2020)

	Yields		**Difference**		**Significance**
Variant	**tons/ha**	**%**	**tons/ha**	**%**	
Control	*7.44*	*100*	*Mt*	-	
$CaCO_3$	*7.96*	*106.94*	*0.51*	*6.94*	-
$CaMg(CO_3)_2$	*7.71*	*103.67*	*0.27*	*3.67*	-
LF 1t/ha	*7.66*	*102.95*	*0.22*	*2.95*	-
LF 3t/ha	*9.81*	*131.79*	*2.36*	*31.79*	***
LF 5t/ha	*8.20*	*110.25*	*0.76*	*10.25*	-
CV 1t/ha	*7.67*	*103.09*	*0.23*	*3.09*	-
CV 3t/ha	*8.19*	*110.03*	*0.74*	*10.03*	-
CV 5t/ha	*8.78*	*118.00*	*1.34*	*18.00*	**
LSD 5%=	*0.959*				
LSD 1%=	*1.322*				
LSD 0.1%=	*1.818*				

The slag remanence was also observed in 2023 when the differences between the experimental variants with slag and the control variant were observed, recording values between 5.16 and 6.35 t/ha, compared to the control variant with 4.65 t/ha .

After 3 years from the application of slag from the steel industry on the reddish preluvosoil, its effect was statistically ensured. Regardless of the dose of CV slag applied, the production of cobs was between 6.16 and 6.35 t/ha. In the variants where LF slag was applied, the cob production was between 5.16 t/ha (in the variant where 1 t/ha of LF slag was applied) and 6 t/ha (in variant p where the maximum dose of slag was applied LF).

Also, in the variants to which the calcareous amendments currently used in agriculture were applied, the production of cobs was higher than in the control variant, registering an increase of 0.9 t/ha (Table 2).

Table 2. The influence of the application of treatments on the production of cobs (year 2023)

	Yields		Difference		Significance
Variant	**tons/ha**	**%**	**tons/ha**	**%**	
Control	*4.65*	*100*	*Mt*	-	
$CaCO_3$	*5.32*	*114.31*	*0.66*	*14.31*	-
$CaMg(CO_3)_2$	*5.54*	*119.11*	*0.89*	*19.11*	*
LF 1t/ha	*5.16*	*110.88*	*0.50*	*10.88*	-
LF 3t/ha	*5.41*	*116.32*	*0.76*	*16.32*	-
LF 5t/ha	*6.00*	*128.84*	*1.34*	*28.84*	**
CV 1t/ha	*6.35*	*136.43*	*1.69*	*36.43*	***
CV 3t/ha	*6.16*	*132.35*	*1.50*	*32.35*	***
CV 5t/ha	*6.17*	*132.49*	*1.51*	*32.49*	***
LDS 5%=	*0.787*				
LSD 1%=	*1.084*				
LSD 0.1%=	*1.490*				

The influence of the application of slag from the steel industry on the production of corn in 2020 was highlighted by very significant increases in the variants on which doses of 3 t/ha and 5 t/ha of steel slag were applied.

The addition of 3 t/ha blast furnace slag (LF) led to an increase in production by 2.62 t/ha compared to the control variant, which obtained a production of 6.1 t/ha. When applying the 5t/ha dose, the production was 7.05 t/ha, 1.7 t/ha lower than the 3t/ha variant.

In the experimental variants on which converter slag (CV) was applied, the productions were significantly increased, the highest production being obtained in the variants on which the dose of 5 t/ha was applied, respectively 7.53 t/ha of grain corn.

All the experimental variants to which the treatments were applied, including calcareous amendments, recorded higher productions than the control variant where the production obtained was 6.1 t/ha (Table 3).

Table 3. The influence of treatment application on maize production (year 2020)

	Yields		Difference		Significance
Variant	**tons/ha**	**%**	**tons/ha**	**%**	
Control	*6.10*	*100*	*Mt*	-	
$CaCO_3$	*6.89*	*113.00*	*0.79*	*13.00*	-
$CaMg(CO_3)_2$	*6.79*	*111.36*	*0.69*	*11.36*	-
LF 1t/ha	*6.62*	*108.57*	*0.52*	*8.57*	-
LF 3t/ha	*8.72*	*142.95*	*2.62*	*42.95*	***
LF 5t/ha	*7.05*	*115.68*	*0.95*	*15.68*	*
CV 1t/ha	*6.82*	*111.85*	*0.72*	*11.85*	-
CV 3t/ha	*7.13*	*116.93*	*1.03*	*16.93*	*
CV 5t/ha	*7.53*	*123.55*	*1.43*	*23.55*	**
LSD 5%=	*0.807*				
LSD 1%=	*1.112*				
LSD 0.1%=	*1.528*				

In the non-fertilized version, the production obtained was 4.16 t/ha of grain corn.

In the variants where calcium carbonate and dolomite were applied, the productions were 4.43 t/ha and 4.41 t/ha of grain corn.

Maize production, after 3 years from the application of the treatments, fluctuated under the influence of the applied amendments but also of the climatic conditions specific to the year 2023.

In the variants on which blast furnace slag (LF) was applied, the productions increased with the increase in the applied dose, the highest production being recorded in the variant on which the dose of 5t/ha was applied, respectively a production of 5.07 t/ha ha grain corn.

Also, in the experimental versions with converter slag (CV), the same trend of production growth was maintained with the increase in the dose of slag applied. The highest production obtained was for the variants on which 5 t/ha of converter slag was applied, respectively 5.47 t/ha of grain corn (Table 4).

Table 4. The influence of treatment application on maize production (year 2023)

	Yields		Difference		Significance
Variant	**tons/ha**	**%**	**tons/ha**	**%**	
Control	*4.16*	*100*	*Mt*	-	
$CaCO_3$	*4.43*	*106.48*	*0.27*	*6.48*	-
$CaMg(CO_3)_2$	*4.41*	*106.08*	*0.25*	*6.08*	-
LF 1t/ha	*4.84*	*116.33*	*0.68*	*16.33*	**
LF 3t/ha	*4.90*	*117.77*	*0.74*	*17.77*	**
LF 5t/ha	*5.07*	*121.85*	*0.91*	*21.85*	***
CV 1t/ha	*4.78*	*114.97*	*0.62*	*14.97*	*
CV 3t/ha	*4.90*	*117.85*	*0.74*	*17.85*	**
CV 5t/ha	*5.47*	*131.46*	*1.31*	*31.46*	***
LSD 5%=	*0.480*				
LSD 1%=	*0.661*				
LSD 0.1%=	*0.909*				

CONCLUSIONS

The research carried out on the red preluvosol from Moara Domneasca, regarding the influence of the application of slag from the steel industry on the corn crop in 2020 and 2023, highlights the beneficial effects brought by the use of these materials on the increase in corn production.

Maize plants recorded the highest height when applying the maximum dose of 5t/ha converter slag (CV), both in 2020 (221.66 cm) and in 2023 (212.66 cm).

Regarding the production of cobs in 2020, the highest was recorded at a dose of 5 t/ha CV slag, with a production of 8.78 t/ha cobs, and in 2023 the highest production was in the version with 1t/ha CV slag, respectively 6.35 t/ha cobs.

In all the experimental variants, both in 2023 and in 2023, grain production was superior to the control variant. Significant productions were recorded in 2020 in the variety with a dose of 3t/ha LF slag, with a production of 8.72 t/ha compared to the control variant where 6.1 t/ha of grains were obtained. In 2023, the highest production was obtained in the version with 5 t/ha CV slag, resective 5.47 t/ha, compared to the control variant with 4.16 t/ha grains.

The use of these products from the steel industry in agriculture can represent a real alternative to traditional raw materials, thus avoiding the consumption of natural resources.

Steel slag has been used successfully as a substitute for limestone, and research has shown that its use is comparable or superior in some cases.

The residual effect of the slag was maintained even after 3 years from its application, the maize production being clearly superior to the control variant.

It is necessary to continue the research to identify the maximum potential of the slag from the steel industry to replace the chemical fertilizers currently used in agriculture.

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