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# RESEARCH ON THE INFLUENCE OF SLAG FROM THE STEEL INDUSTRY ON THE REDDISH PRELUVOSOIL IN WHEAT CULTIVATION

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***Abstract***

*Materials from the steel industry can be successfully used in agriculture, mainly due to their high content in Calcium and other nutrients. In order to follow up on the influence of these materials, an experiment was carried out in 2021, at Moara Domnească, in the Muntenia region, Romania, on a reddish preluvosoil cultivated with wheat. The effects of two types of materials from the steel industry on the acidity of the soil, on the content of heavy metals found in the soil and on their translocation in wheat plants was analyzed. Research has shown that by applying maximum doses of 5 tonnes/ha, these materials increase the soil's pH reaction and the agricultural production, without the risk of heavy metals translocating in wheat plants.*

***Key words****: amelioration, wheat production, heavy metal, soil fertility, steel slag.*

## INTRODUCTION

Mineral lime is normally applied to correct soil acidity, but is impractical in many developing countries due to supply shortages and higher costs (Xu & Coventry, 2003; Li et al., 2010). Additionally, mineral lime cannot effectively increase the contents of K, Mg, and P in acidic soils (Sun et al., 2000). Consequently, some researchers have turned their attention to industrial by-products, with the aim of finding new methods for ameliorating acidic soils (Illera et al., 2004; Li et al., 2010; Shi et al., 2016). Some industrial by-products contain not only alkaline substances but also nutrients such as Ca, Mg, K and P, that are important for plants. Therefore, the incorporation of these industrial by-products into acidic soils can not only neutralize soil acidity but can also increase the contents of nutrients found in the soil. Agricultural use of industrial by-products is also a less expensive disposal method.

With the rapid growth of the world population, similarly to other industries, steel industries are also more concerned about the safe and eco-friendly recycling of their by-products.

In the past, the steel industries were designed to produce iron and steel of a specific quality and quantity (Das et al., 2019). With the rapid growth of industrialization in recent decades, the increased volume of by-products (slag) resulted from iron/steel production has drawn attention to the need for its more effective recycling (Das et al., 2019). Slags are widely used worldwide as a substitute for limestone and offer a cost-effective advantage to farmers. The main aim for researchers and environmentalists is to stop the entry of metals and metalloids into the food chain, for better human health (Kimio, 2015; Brevik et al., 2012), and in this respect, the use of slags in various fields can help cope with this problem (Kimio, 2015).

In the soil medium, the highest concentrations of potentially toxic elements that cause plant toxicity are represented by cadmium (Mehmood et al., 2017), lead (Mehmood et al., 2017), zinc (Hafeez et al., 2013), copper (Bashir et al., 2018), nickel (Tariq et al., 2018), vanadium (Imtiaz et al., 2018) and arsenic (Hettick et al., 2015).

The use of slag as a fertilizer increases phosphorus (Yang et al., 2009), calcium, and magnesium (Castro & Crusciol, 2013) availability for the plants. Calcium and magnesium form inorganic ionic pairs with minerals present on the surface of the slag that is used as a fertilizer (Gonzalo et al., 2013; Wu et al., 2013). It was concluded by Fan et al. (2018) that the use of slag as a fertilizer has the ability to decrease the content of Cr, Cu, Pb and Zn in acidic soils and the authors indicated that slag could be used in PTE pollution control for plants and the environment.

The long-term application of slag on the soil increases the soil's organic carbon contents, due to lower carbon mineralization rates (Wang et al., 2020). Additionally, slag contains ferric oxide on its surface, which could also increase the soil's carbon storage (Ali et al., 2013; Wang et al., 2012). Moreover, other than the improvement of soils, plant growth and yield are high priorities for sustainable agricultural progress (Rai et al., 2019).

## MATERIALS AND METHODS

The experiment was carried out in 2021, in the experimental field of the Faculty of Agriculture from Moara Domnească, on reddish preluvosoil.

Reddish preluvosoil is characterized, in the surface horizon (Ao), by the following properties: humus content - 2.4%, clay-loamy texture, soil pH reaction between 5.2 and 5.4, and the degree of base saturation between 65-70% (Mihalache et al., 2014).

In order to follow up on the effect of slag on the soil's chemical properties and on the yield of wheat, the experimental field had nine variants, in three repetitions: V1 (control), V2 (2 tons/ha-$CaCO_3$), V3 (2 tons/ha-$CaMg(CO_3)_2$), V4 (1 ton/ha-furnace slag), V5 (3 tons/ha-furnace slag), V6 (5 tons/ha-furnace slag), V7 (1 ton/ha-converter slag), V8 (3 tons/ha-converter slag) and V9 (5 tons/ha-converter slag).

Figure 1. The experimental field from Moara Domnească, Ilfov County, Muntenia Region, Romania (2021)

Fertilization with 100 kg of nitrogen was also applied, in order to follow up on the combined effect of the amendment and nitrogen fertilizer on the wheat yield. Soil samples were collected in the 0-20 cm and 20-40 cm depth in all experimental variants in order to verify the influence on the soil's pH reaction and to correlate these results with its influence on the wheat yield.

## RESULTS AND DISCUSSIONS

It was shown that applying soil amendments improved the chemical properties of the reddish preluvosoil by increasing the soil's pH reaction, in some correlation with the application dosage of the slags and depending on the application of the amendment (Tables 1 and 2).

The application of different quantities of slag in the spring of 2020 led to a change in the soil's pH reaction at a depth of 0-20 cm in all experimental variants.

The most significant increase, compared to the control variant, where the pH had a value of 5.86, was recorded in the V9 variant, where converter slag was applied in a dose of 5 tonnes per hectare, where the pH value increased by more than one unit, respectively up to a pH of 7.29 (Table 1).

Table 1. Variation of the soil's pH reaction on the depth of 0-20 cm (2021)

| Variant | Soil's pH | | Difference | | Significance |
|---|---|---|---|---|---|
| | | % | | % | |
| V1-control | 5.86 | 100 | Mt | - | |
| V2-$CaCO_3$ | 6.05 | 103.29 | 0.19 | 3.29 | * |
| V3-$CaMg(CO_3)_2$ | 6.16 | 105.11 | 0.3 | 5.11 | ** |
| V4-LF 1 tonne/ha | 6.06 | 103.35 | 0.19 | 3.35 | * |
| V5-LF 3 tons/ha | 6.23 | 106.36 | 0.37 | 6.36 | *** |
| V6-LF 5 tons/ha | 6.22 | 106.19 | 0.36 | 6.19 | *** |
| V7-CV 1 ton/ha | 6.12 | 104.49 | 0.26 | 4.49 | ** |
| V8-CV 3 tons/ha | 6.18 | 105.45 | 0.32 | 5.45 | ** |
| V9-CV 5 tons/ha | 7.29 | 124.33 | 1.42 | 24.33 | *** |
| *LSD 5% = 0.183*<br>*LSD 1% = 0.252*<br>*LSD 0.1% = 0.346* | | | | | |

At a depth of 20-40 cm, the soil's pH reaction also increased in all experimental variants, with the pH value increasing from 5.82, in the control variant, to 7.16 in the V9 variant, where converter slag was applied in a dose of 5 tonnes/ha (Table 2).

Table 2. Variation of the soil's pH reaction on the depth 20-40 cm (2021)

| Variant | Soil's pH | | Difference | | Significance |
|---|---|---|---|---|---|
| | | % | | % | |
| V1-control | 5.82 | 100 | Mt | - | |
| V2-$CaCO_3$ | 6.07 | 104.29 | 0.25 | 4.29 | ** |
| V3-$CaMg(CO_3)_2$ | 6.14 | 105.43 | 0.31 | 5.43 | ** |
| V4-LF 1 ton/ha | 5.95 | 102.11 | 0.12 | 2.11 | - |
| V5-LF 3 tons/ha | 6.15 | 105.66 | 0.33 | 5.66 | *** |
| V6-LF 5 tons/ha | 6.11 | 104.97 | 0.29 | 4.97 | ** |
| V7-CV 1 ton/ha | 6.15 | 105.54 | 0.32 | 5.54 | ** |
| V8-CV 3 tonnes/ha | 6.25 | 107.37 | 0.43 | 7.37 | *** |
| V9-CV 5 tons/ha | 7.16 | 122.88 | 1.33 | 22.88 | *** |
| *LSD 5% = 0.172*<br>*LSD 1% = 0.237*<br>*LSD 0.1% = 0.326* | | | | | |

Table 3. Biomass production obtained when the wheat samples were harvested

| Variant | Production | | Difference | | Significance |
|---|---|---|---|---|---|
| | t/ha | % | t/ha | % | |
| V1-control | 7.07 | 100 | Mt | - | |
| V2-$CaCO_3$ | 8.42 | 119.09 | 1.35 | 19.09 | ** |
| V3-$CaMg(CO_3)_2$ | 8.41 | 118.95 | 1.34 | 18.95 | ** |
| V4-LF 1 ton/ha | 8.58 | 121.40 | 1.51 | 21.40 | ** |
| V5-LF 3 tons/ha | 9.30 | 131.54 | 2.23 | 31.54 | *** |
| V6-LF 5 tons/ha | 9.41 | 133.14 | 2.34 | 33.14 | *** |
| V7-CV 1 ton/ha | 8.36 | 118.29 | 1.29 | 18.29 | ** |
| V8-CV 3 tons/ha | 9.06 | 128.24 | 1.99 | 28.24 | *** |
| V9-CV 5 tons/ha | 9.40 | 132.95 | 2.33 | 32.95 | *** |
| *LSD 5% = 0.684*<br>*LSD 1% = 0.942*<br>*LSD 0.1% = 1.296* | | | | | |

The above-ground biomass production resulting from the wheat harvest recorded significant increases for the variants where doses of 3 tons/ha and 5 tons/ha were applied, in both the case of LF and CV slag.

Regarding the wheat production obtained in the climatic conditions of 2021, it can be seen that, in the variants where $CaCO_3$ and CaMg $(CO_3)_2$ was applied, in a dose of 2 tons/ha, the production recorded distinctive and significant increases of up to 6.83 tons/ha, in the case of $CaCO_3$ and of 7.06 tonnes/ha, in the case of $CaMg(CO_3)_2$ when compared to the control variant, where the production was of 6.28 tonnes/ha (Table 4).

Table 4. The influence of applied amendments on wheat production

| Variant | Production | | Difference | | Significance |
|---|---|---|---|---|---|
| | t/ha | % | t/ha | % | |
| V1-control | 6.28 | 100 | Mt | - | |
| V2-$CaCO_3$ | 6.83 | 108.64 | 0.54 | 8.64 | ** |
| V3-$CaMg(CO_3)_2$ | 7.06 | 112.40 | 0.78 | 12.40 | ** |
| V4-LF 1 ton/ha | 7.13 | 113.41 | 0.84 | 13.41 | ** |
| V5-LF 3 tons/ha | 7.30 | 116.11 | 1.01 | 16.11 | *** |
| V6-LF 5 tons/ha | 7.62 | 121.31 | 1.34 | 21.31 | *** |
| V7-CV 1 ton/ha | 7.12 | 113.30 | 0.83 | 13.30 | ** |
| V8-CV 3 tons/ha | 7.37 | 117.33 | 1.09 | 17.33 | *** |
| V9-CV 5 tons/ha | 7.94 | 126.29 | 1.65 | 26.29 | *** |
| *LSD 5% = 0.468*<br>*LSD 1% = 0.645*<br>*LSD 0.1% = 0.887* | | | | | |

In the variants where slag from the steel industry was applied, the highest production was recorded for the V9 variant, with a dose of 5 tons/ha of converter slag, respectively a production of 7.94 tons/ha, but very significant increases in the production were also recorded in all other doses applied, when compared to the control variant.

The content of heavy metals (Cu, Zn and Pb) recorded in wheat grains was under the maximum permissible limits.

There were no increases in the quantity of heavy metals found, even with the increase of the doses of slag applied.

The lead content in wheat grains was of 0.5-1.6 mg/kg, the Cu content was of 2.5-5.5 mg/kg and the Zn content was of 18.5-32.7 mg/kg (Figures 2, 3, 4).

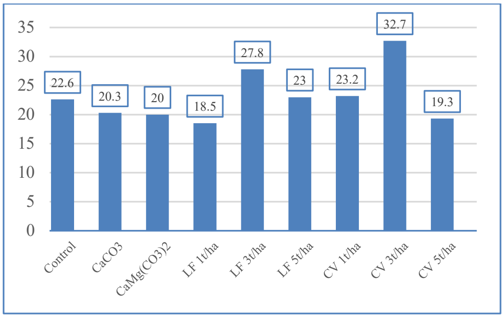

Figure 2. Zinc content in wheat grains (mg/kg)

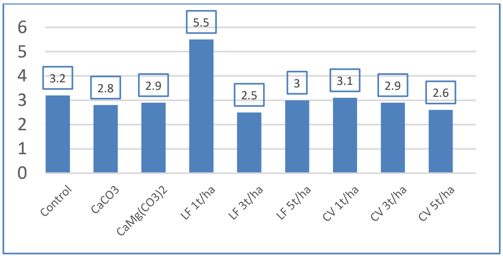

Figure 3. Copper content in wheat grains (mg/kg)

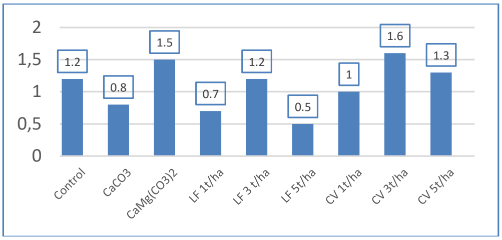

Figure 4. Lead content in wheat grains (mg/kg)

The highest concentrations of heavy metals were recorded at the following doses: Zn - 32.7 mg/kg in the V8 variant, where CV slag was applied at a dose of 3 tonnes/hectare, Cu - 5.5 mg/kg in the V4 variant, where LF slag was applied in a dose of 1 ton/hectare and Pb - 1.6 mg/kg for the V8 variant, where CV slag was applied in a dose of 3 tons/hectare. Cd, Co and Cr were below detection limits.

## CONCLUSIONS

Improving the reaction of the soil with by-products from the steel industry improves the conditions for the growth and development of crop plants by neutralizing the soil's acidity, by increasing the nutrient content in the soil and by offering a better nutrient accessibility for crop plants.

Slag from steel factories can be used with good results in agriculture, as it has significant positive influences on both the soil and the plants cultivated - in this case, on wheat cultivation.

Biomass production was higher in all experimental variants, when compared to the control variant.

The research also focused on the behaviour and immobilization in soil and plants of the main heavy metals contained in slag, in order to achieve a more efficient and sustainable use of this by-product in agriculture. The application of slag did not cause the accumulation of heavy metals in wheat grains, recording values below the maximum permissible limits, even at the maximum doses applied.

In order to avoid the accumulation of heavy metals in the soil and in the plants, we recommend not to exceed the dose of 3 tonnes/ha of slag, applied once every 4 years.

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