IMPACT OF COAL ASH AND PHOSPHOGYPSUM APPLICATION ON SOIL FERTILITY OF CHERNOZEM SOILS OF NORTH KAZAKHSTAN

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Abstract. Industrial waste stocks in Kazakhstan significantly increase and only 10-15% of total generated industrial waste is utilized. Industrial waste dumps occupy large areas, have negative impact on the environment and degradation of landscape. Sustainable waste management strategy leads to waste recycling and development of new waste recycling technologies. The coal ash and phosphogypsum usage as soil fertilizers is appropriate, however, there is a need for additional investigation of ecological risks related with this industrial waste utilization technology. The aim of this research is to investigate the effect of phosphogypsum and coal ash application on North Kazakhstan chernozem soils in production conditions. There was phosphogypsum and coal ash application influence tested on the soil fertility, food safety and crop yield. Three experimental fields, with the area of 10 ha each, were developed and investigated since 2014. For coal ashes (200 kg·ha⁻¹), phosphogypsum (1 t·ha⁻¹) and control experimental fields different fertilization plans were defined. The soil samples were collected three times a year and the initial content of humus, pH, plant nutrient elements and heavy metal content of the soil were tested in laboratory. The experiment results in general show positive effect on soil fertility and crop yield. The wheat yield was significantly higher in coal ash (30.0 c·ha⁻¹) and phosphogypsum (24.0 c·ha⁻¹) fields comparing with the control field (15.9 c·ha⁻¹). Nitrogen was in the same level (38.8-37.6 mg·kg⁻¹) in all three experimental fields, however, potassium was higher in the coal ash field. The results in pH show the neutralization process in soil environment. There is still a need for additional research to be done in case of heavy metal accumulation and the impact on food safety.

Keywords: phosphogypsum, coal ash, macronutrient, micronutrient elements, heavy metals, crop yield, spring wheat, maximum allowable concentration.

Introduction

The amount of fertilizer application in the Republic of Kazakhstan significantly reduced – for instance, the usage of mineral fertilizers (fell down from 970 thousand tons in 1985 to 43 thousand tons in 2004) and as for organic fertilizers (decreased from 120-130 thousand tons in 1985 compared to 22 million tons in 1990), what consequently caused a negative balance of nutrient elements in the soil [1].

The removal of nutrient elements is not significantly compensated, for comparison – on a global scale, the deficiency is replenished by 48 %, in developed countries - by 60-90 %, and in Kazakhstan – no more than 10 % [2].

For full-fledged growth and development of the plant organism, the application of only mineral or organic fertilizers is not enough. The role of macronutrient and micronutrient elements in plant development is multifaceted. In particular, the trace elements copper (Cu), molybdenum (Mo), manganese (Mn), cobalt (Co), zinc (Zn), boron (B) increase the activity of many enzymes and enzyme systems in the plant organism and improve the use of macronutrients from the soil. Optimal is the simultaneous inflow of macro- and micronutrient elements, especially for phosphorus and zinc, nitrogen and molybdenum [5; 6].

The possibilities of applying industrial waste for soil fertilization with macro- and micronutrient elements are still very little used [7; 8]. According to the number of conducted research works, the use of phosphogypsum and ash as an ameliorant and fertilizer, due to the high content of a number of elements (K, Na, Zn, Ca, Mg and Fe), improves the agrophysical properties of the soil, enriches it with macro- and micronutrient elements amount, increases the yields of agricultural crops [3; 4].

Microelement nutrition of plants in conditions of chernozem soils of Northern Kazakhstan remains poorly studied. The study of the effectiveness of application of industrial waste as a microfertilizer has not been conducted previously in the conditions of North Kazakhstan.

The objects of the research are the ordinary chernozem and spring wheat “Astana”. The subject of the research are phosphogypsum and ash.

The aim of the research is to investigate the effect of phosphogypsum and coal ash on the macro- and micronutrients provision of chernozem ordinary.
The following tasks were set to study the effect of coal ash and phosphogypsum on:
1. the content of macro- and micronutrients in the soil;
2. the content of heavy metals in the soil;
3. the crop productivity of spring wheat.

The hypothesis set for the research is that balanced applying of phosphogypsum and coal ashes, which have both the soil amending and nutrient-enriching properties, is helpful in improving nutritious mode and acidity of soils and ecological safety.

Materials and methods

The experiments of application of phosphogypsum and industrial ashes impact were carried out in production conditions in “Umai-Zher” LLP, Zerendinsky district, Akmola region, with total area of 262 hectares.

The soils of the territory are presented mostly by a background of the ordinary and southern carbonate chernozems of medium thickness and with low-humus content.

The experiment was conducted according to the following scheme:
1. control - without fertilizer;
2. phosphogypsum – 1 t·ha\(^{-1}\);
3. coal ash - 0.2 t·ha\(^{-1}\).

In May 2015, ash and phosphogypsum were introduced to the soil by the KSA-3 spreader according to the scheme above. Fertilizers were embedded in the soil with disc harrows BDT-7 to a depth of 8-10 cm. The soil was treated by the type of the steam system of crop rotation. According to the ecological rationing of application of phosphogypsum and ashes they are recommended for crop fertilization 1 time in 4 years, with further monitoring of ecological safety of soils and products.

Coal ash was taken from the ash dumps of the district boiler house of Kokshetau, phosphogypsum – from the dumps of Kazphosphate LLP, Stepnogorsk. In 2016, spring wheat was sown by zone technology. The research applied the quantitative method in analysis.

The following observations were made in the experiment:
- organic matter of soil (humus) by the method of Tyurin in the modification of Nikitin, GOST 26231-91;
- easily hydrolyzed nitrogen - the method of Tyurin and Kononova;
- mobile compounds of phosphorus and potassium – by the method of Machigin in the modification of CINAO, GOST 26205-91;
- pH of water extract by the potentiometric method, GOST 26423-85;
- heavy metals in soil by the method of inversion voltammetry, GOST 50686.

Results and discussion

As a result of the application of phosphogypsum and ash, there was an increase in the content of the nutrient elements relative to the control variant. Optimal amount of nutrients in the soils should be as follows: mobile phosphorus – 30 mg·kg\(^{-1}\), nitrate nitrogen 12-15 mg·kg\(^{-1}\), potassium - 400 mg·kg\(^{-1}\)).

The availability of mobile phosphorus on the control was low - 14.1 mg·kg\(^{-1}\), with insignificant increase - up to 14.3 and 14.5 mg·kg\(^{-1}\) on the options of ash and phosphogypsum, respectively. The initial content of nitrate nitrogen was also low - 37.6 mg·kg\(^{-1}\), with an increase to 38.1 and 38.8 mg·kg\(^{-1}\) on the fertilized variants. The potassium supply is high, which can be seen from Table 1. The fertilizers in the steam system contributed to a decrease in the pH value to 6.7 and 6.82 (at the control it was 7.5).

The data in Table 2, it follows that during the vegetation period in 2016, the availability of mobile phosphorus on the control is characterized as low (according to Machigin's division). The applying of ash contributed to a slight improvement in the phosphorus nutrient regime (on average higher by 11.4 % than the control variant). On the phosphogypsum variant, there was a significant increase in the availability of exchange phosphorus in soil (on average it is higher by 23.5 % compared with the control).
Influence of phosphogypsum and ash on the main indices of fertility of chernozem in steam system, 2015

<table>
<thead>
<tr>
<th>Experiment variants</th>
<th>Nutrient element amount, mg·kg⁻¹</th>
<th>Humus, %</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>N</td>
</tr>
<tr>
<td>Control</td>
<td>14.1</td>
<td>457</td>
<td>37.6</td>
</tr>
<tr>
<td>Coal Ash 0.2 t·ha⁻¹</td>
<td>14.3</td>
<td>452</td>
<td>38.1</td>
</tr>
<tr>
<td>Phosphogypsum 1 t·ha⁻¹</td>
<td>14.5</td>
<td>449</td>
<td>38.8</td>
</tr>
</tbody>
</table>

Main indicators of fertility of chernozem in spring wheat crops, depending on the application of phosphogypsum and coal ash, 2016

<table>
<thead>
<tr>
<th>No</th>
<th>Nutrient element amount, mg·kg⁻¹</th>
<th>Humus, %</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>*</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td>2</td>
<td>*</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td>3</td>
<td>*</td>
<td>**</td>
<td>***</td>
</tr>
</tbody>
</table>

* – before sowing, ** – tillering phase, *** – before harvesting
Row No.: 1 – control, 2 – coal ash, 3 – phosphogypsum

On the control variant, the content of nitrate nitrogen before sowing was 47.2 mg·kg⁻¹ (medium content), in the tillering phase – 28.0 and before harvesting - 26.9 mg·kg⁻¹ (low content). In the variants with adding ash and phosphogypsum, the amount of nitrate nitrogen was significantly higher than in the control plot. The application of phosphogypsum and ash had no significant effect on the dynamics of the content of exchangeable potassium in the soil. However, in the ash variant, the content of exchangeable potassium increased by 7.7 % with respect to the control. In general, the availability of exchangeable potassium in all variants of the experiment was high.

The reaction of the soil pH in all variants was characterized as neutral.

In 2015, in the steam system, the provision of soil microelements on the control was as follows: copper – was low, zinc – medium, molybdenum – low content. A significant increase in the molybdenum content was noted for the ash variant – up to 0.09 mg·kg⁻¹. In this variant, an increase in the copper content to an average availability (1.90 mg·kg⁻¹) was observed, and the phosphogypsum variant rose up to a high content (8.4 mg·kg⁻¹). On fertilized variants, the zinc content increased insignificantly, as it can be seen from Table 3.

Influence of application of phosphogypsum and coal ash on micronutrient element amount in the soil, mg·kg⁻¹

<table>
<thead>
<tr>
<th>The experiment variants</th>
<th>Pb</th>
<th>Cd</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.70</td>
<td>1.80</td>
<td>0.04</td>
<td>0.96</td>
</tr>
<tr>
<td>Coal ash 0.2 t·ha⁻¹</td>
<td>2.90</td>
<td>6.70</td>
<td>0.03</td>
<td>1.90</td>
</tr>
<tr>
<td>Phosphogypsum 1 t·ha⁻¹</td>
<td>1.50</td>
<td>5.10</td>
<td>0.06</td>
<td>8.40</td>
</tr>
</tbody>
</table>

Permissible heavy metals rates in accordance with legislation

The chemical content of phosphogypsum and ashes, which is characterized by SiO2, Al2O3, Na2O,Pb2O5,CaO, Fe2O3, MgO, K2O and etc. influenced rises of the micronutrient element content in the soil. In 2016, on spring wheat sowings, on the control variant the copper supply was characterized as high, the content of zinc average. On the ash variant, the copper supply was average and was at the control level (4.0 mg·kg⁻¹); the phosphogypsum variant showed a noticeable increase in the zinc content.
up to a high content (8.0 mg·kg\(^{-1}\)). A significant accumulation of lead was noted on the variant of ash application 6.7 mg·kg\(^{-1}\) and phosphogypsum 5.1 mg·kg\(^{-1}\), which exceeds the control by 4.9 and 3.3 mg·kg\(^{-1}\), respectively. In the application of ash and phosphogypsum there was an increase in the zinc content by an average of 2.3 and 2.6 mg·kg\(^{-1}\), respectively to the control plot.

The introduction of phosphogypsum and ash did not affect the ecological safety of wheat crops and soil, the content of heavy metal elements in them did not exceed the maximum allowable standards. The noted optimization of the level of mineral nutrition with macro- and microelements contributed to an increase in the crop yield of spring wheat. On the control variant, its yield was 15.9 c·ha\(^{-1}\), for the coal ash variant – 30.0 c·ha\(^{-1}\) and for the phosphogypsum variant – 24.0 c·ha\(^{-1}\).

**Conclusions**

The application of phosphogypsum and coal ashes for fertilization of the soils in Akmola region lead to intensive soil aggregation and creation of a soil structure that is favourable for crops, which:

- influenced the growth of soil nutrient elements, such as the content of nitrate nitrogen, mobile phosphorus, copper, zinc;
- impacted on neutralization of the soil environment;
- met sanitary and toxicological standards.

Improvement of the macro- and microelements’ availability in the soil contributed to an increase in the crop yield of spring wheat grains by 14.1 and 8.1 c·ha\(^{-1}\), respectively, or by 88.7 % and 50.9 % in comparison with the control.

The research needs to be continued to investigate further Cu, Zn, Cd, Pb content data during crop rotation to study the heavy metal concentrations on chernozem soils and the cumulative impact of influence of the fertilizers on the productivity of crops with further implementation and development of this innovative experience in other regions.

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