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

Altynay Rakhimova[1], Abilzhan Khussainov[1], Inga Grinfelde[2]
[1]Shokan Ualikanov Kokshetau State University, Kazakhstan; [2]Latvia University of Agriculture
rakhimova_altynay@mail.ru, abil_tokan_@mail.ru, inga.grinfelde@gmail.com

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 some 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, macronutruient, 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 $t \cdot ha^{-1}$;
3. coal ash - 0.2 $t \cdot ha^{-1}$.

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 $mg \cdot kg^{-1}$, nitrate nitrogen 12-15 $mg \cdot kg^{-1}$, potassium - 400 $mg \cdot kg^{-1}$). The availability of mobile phosphorus on the control was low - 14.1 $mg \cdot kg^{-1}$, with insignificant increase - up to 14.3 and 14.5 $mg \cdot kg^{-1}$ on the options of ash and phosphogypsum, respectively. The initial content of nitrate nitrogen was also low - 37.6 $mg \cdot kg^{-1}$, with an increase to 38.1 and 38.8 $mg \cdot kg^{-1}$ 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).

From 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).

Table 1

Influence of phosphogypsum and ash on the main indices of fertility of chernozem in steam system, 2015

Experiment variants	Nutrient element amount, mg·kg^{-1}			Humus, %	pH
	P_2O_5	K_2O	N		
Control	14.1	457	37.6	3.1	7.53
Coal Ash 0.2 t·ha^{-1}	14.3	452	38.1	3.3	6.70
Phosphogypsum 1 t·ha^{-1}	14.5	449	38.8	3.5	6.82

Table 2

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

No	Nutrient element amount, mg·kg^{-1}									Humus, %			pH		
	P_2O_5			K_2O			N								
	*	**	***	*	**	***	*	**	***	*	**	***	*	**	***
1	13.2	14.5	10.4	625	507	571	47.2	28.0	26.9	4.55	4.41	4.12	7.0	6.9	7.0
2	13.6	15.1	11.6	639	496	615	49.3	38.6	29.1	4.73	4.80	4.49	6.9	7.0	6.9
3	18.2	15.6	12.9	656	561	571	58.8	49.8	29.4	4.58	4.46	4.31	6.9	7.0	7.0

* – 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.

Table 3

Infuence of application of phosphogypsum and coal ash on micronutrient element amount in the soil, mg·kg^{-1}

The experiment variants	Pb		Cd		Cu		Zn	
	2015	2016	2015	2016	2015	2016	2015	2016
Control	1.70	1.8	0.04	0	0.96	4.0	1.1	1.2
Coal ash 0.2 t·ha^{-1}	2.90	6.7	0.03	0	1.90	4.0	1.24	2.3
Phosphogypsum 1 t·ha^{-1}	1.5	5.1	0.06	0	8.40	8.0	0.55	2.6
Permissible heavy metals rates in accordance with legislation	32		3		33		23	

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

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 phosphogypsym 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.

References

1. Елешев Р.Е. Состояние и перспективы развития агрохимических и агроэкологических исследований в Республике Казахстан (State and prospects of development of agrochemical and agroecological research in the Republic of Kazakhstan). Журнал Почвоведение и агрохимия, 2008, № 1. (in Russian)
2. Елешев Р.Е. Почвы Казахстана и приоритеты их сохранения и воспроизводства (Soils of Kazakhstan and the priorities of their conservation and reproduction. Материалы Международной научно-практической конференции: Новая стратегия научно-образовательных приоритетов в контексте развития АПК, 2015. (In Russian).
3. Basu M., Pande M., Bhadoria P.B.S., Mahapatra S.C. Potential fly-ash utilization in agriculture: A global review. Progress in Natural Science, vol. 19, 2009, pp. 1173-1186.
4. Mittra B.N., S. Karmakar, D.K. Swain, B.C. Ghosh. Fly Ash – a Potential source of soil amendment and a component of integrated plant nutrient supply system. International Ash Utilisation Symposium, Center for Applied Energy, 2003. [Online]. (01.03.2003). Available at: http://www.flyash.info/2003/28mit.pdf.
5. Добрыднев Е., Локтионов М., Шумкова Н. Основные результаты изучения агроэкологической эффективности фосфогипса в сельском хозяйстве Краснодарского края. Плодородие.Main Results of Studying the Agroecological Efficiency of Phosphogypsum in the Agriculture of Krasnodar Region. Fertility. (In Russian). [online] (01.02.2013). (In Russian).
6. Available at: http://www.penzgtu.ru/fileadmin/filemounts/science/xxi_pub/2013_13_2.pdf.
7. Галич С. А. Перспективы использования золошлаков ТЭС в качестве микроудобрения для почв. (Prospects of the Application of Coal Ashes of Thermal Power Plant as Microfertilizer for Soils). Institute of Problems of Mechanical Engineering of National Academy of Sciences of Ukraine, Kharkiv, Ukraine. (In Russian). [online] (20.03.2010). Available at: http//www.waste.com.ua.
8. Garg, R., Pathak, H., Das, D., Tomar, R. (2005). Use of Flyash and Biogas Slurry for Improving Wheat Yield and Physical Properties of Soil. Environmental Monitoring and Assessment. [online] (02.08.2004). Available at:

http://link.springer.com/article/10.1007 %2Fs10661-005-2021-x.
9. Ахмедьянов А., Киргизбаева К., Туреханова Г. Вторичная переработка отходов (золошлаков) промышленных предприятий. (Secondary Processing of Wastes (Coal Ashes) of the Industrial Enterprises). (In Russian). [online] (20.03.2010). Available at: http://www.kap.kz/upload/files/27144_989850_15.pdf.