Effectiveness of the Alternative Fertilizer Application on Spring Wheat on Chernozem Soils in Northern Kazakhstan

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***Abstract*—Industrial wastes are considered as technogenic and mineral raw materials, which have an accumulation capability, rather than being depleted, in comparison to natural resources. Thus, such raw materials are prospective topic to study in order to apply them for agricultural production. The isolation of valuable components and non-waste utilization technologies could help to solve number of problems by exploiting them in agriculture, such as freeing up areas with piles of waste and reducing their negative impact on environment. This paper presents the results of a study on application of various types of industrial wastes on spring wheat fields on chernozem soils in the condition of the Northern Kazakhstan between a period of 2014 and 2015. Experimental design based on comparison of treatments with industrial waste, e.g. phosphogypsum, fly ash, new product called "Agrobionov", which based on byproducts of carbon and fly ash, with other phosphate fertilizers, e.g. superphosphate, phosphate rock.**

***Keywords*— chernozem, industrial waste, spring wheat.**

I. Introduction

Chemical fertilizers are a vital part of modern agriculture in Kazakhstan, where more than half of its arable lands have low humus content (2-4%) and nearly 18 million hectares of arable lands have very poor content of phosphorus. A sharp decline in the application of mineral fertilizers in the Republic of Kazakhstan was observed since 1987. Significant reduction of the use of synthetic fertilizers leads to a severe nutrient deficiency in the soil, which resulted to the depletion of arable land and the drop in overall agricultural productivity. The resulting nutrient balance for the last 10 years was negative for all nutrient supply in the soil. These changes have many consequences, for the most part, a highly negative that cause a low agricultural output. According to many years of soil research, chernozem soils lost about 25-27% of their natural humus content, which is a main indicator of soil fertility [1-4]. Therefore, the most promising solution to solve this problem might be the application new fertilizers produced from industrial and other cheap local wastes.

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Recycling industrial waste to improve soil fertility is a promising direction in agriculture. Along with solving food crisis, it also helps with utilization problem of solid waste from local industries [5].

According to the Departments of Natural Resources and Environmental Control, a total of 202.5 million metric tons of slag were produced in Akmola, Kostanay, Pavlodar and the Northern Kazakhstan regions, including 9 million tons of phosphogypsum formation only from Stepnogorsk city.

The use of slag and fly ash wastes in agriculture would not only have environmental benefits, but also economic, agrochemical and agronomic values, due to a price reduction for restoring soil fertility and for cheap land reclamation [6].

Many scientists discovered ameliorative effect of various industrial wastes on soil properties [7-11].

The main purpose of this study is to explore the direct effect and residual effect of various industrial wastes on the chernozem soil fertility and spring wheat productivity in the conditions of Northern Kazakhstan.

II. Materials and Methods

A field experiment on yield response of spring wheat to different types of alternative fertilizers was conducted at the research farm of Ltd "Agricultural Scientific Institute of North Kazakhstan", located in the Chaglinka village, Akmola region (53° 10′ 9.12″ N, 69° 7′ 37.57″ E 53.1692°, 69.127103°). In our experiment, the "Astana", local wheat variety, was cultivated by using a zonal tillage. According to the Redkova's soil classification system the soil type of the experimental plot was ordinary chernozem, medium loamy with low humus content and heavy clay [12]. The topsoil contains 3.41% of humus, 30.8 mg/kg of readily hydrolysable nitrogen, 9.0 mg/kg of active phosphorus compounds and 596.6 mg/kg soil potassium. Soil reaction or soil pH is slightly alkaline of 7.5.

The experimental plots were laid out in systematic approach method with three replicates. The experimental design includes the following treatments: (1) control, (2) superphosphate - 20 kg/ha (as it was a recommended rate for this area), (3) phosphogypsum - 3 t/ha, (4) fly ash - 0.4 t/ha, (5) Agrobionov - 0.4 t/ha and (6) phosphate rock – 0.3 t/ha.

The fertilizer "Agrobionov" was produced in the LLC Research and Industrial Association, "AgroBioTechnovacii", Omsk city, by Sarsenova A.A. Main ingredients: Carbon, Silica, Aluminum, Iron; and macro-elements, e.g. Calcium, Sulfur, Magnesium, and Sodium. Product moisture content – 14-30%, bulks density – 610 kg/m^3, particle size – 0.6-0.5 mm.

Fly ash was obtained for experimental purposes from the

Stepnogorsk Thermal Power Plant. The chemical composition of fly ash was as following: Na_2O – 1.15%, MgO – 1.20%, Al_2O_3 – 23.52%, SiO_2 – 53.22%, P_2O_5 – 0.36%, K_2O – 1.60%, CaO - 3.36%, TiO – 1.23%, Mn – 0.08%, Fe_2O_3 – 7.21%, and others – 7.05%.

Phosphogypsum is an industrial by-product, which is formed during the phosphate fertilizer production process and regarded as one of the most accumulated industrial waste. Moreover, the phosphogypsum is a final product of mechanical and chemical processing of natural apatite. It has a strong acid reaction (pH) of 4.5-5.0. Ancient deposits of phosphogypsum in Kazakhstan are located in the territory of Ltd "Stepnogorsk Mining and Chemical Combine". The chemical composition of the phosphogypsum deposits in Karatau left from the production of phosphate fertilizers include: CaO – 33.5%, Mg – 0.17%, Al_2O_3 – 0.66%, SO_2 – 49.0%, P_2O_5 – 1.6-2%, F – 0.3%, Sr – 0.13%, and insolubles – 15%.

Soil samples were taken from depths of 0-20 cm for the following analysis: to determine the content of the easily hydrolysable nitrogen according to the methodology of I.V. Turin and M.M. Kononova and to determine the active phosphorus and potassium levels according to the methodology of Machigin, as well as to determine the soil microbiological activity by methods of flax cloth by E. N. Mishustin.

III. Results and Discussion

The amount of precipitation and air temperature significantly influenced to the spring wheat growth and development, as well as its yield attributes during the crop-growing season. Average precipitation during the period of May and August in 2014 amounted to 259.4 mm, while in 2015, it was 155.9 compared to the mean long-term annual rate of 185.1 mm. Air temperature during the growing season was the same as the average annual temperature of 14.3^0C.

As it is widely known, microbiological activity plays an essential role in the degradation of soil organic matter and in the maintenance of soil nutrient regime. Soil microbial biomass and microbial activity are the major soil quality indicators [13, 14].

The rate of decomposition of linen cloth shows the activity of cellulose feeding bacteria. The overall process of cellulose degradation depends on the microbial population, and microbial composition, as well as their activity.

According to the current research findings, application of various industrial wastes positively affected to soil microbial activity compared to control treatment (Table 1). During the experimental two years, the most active cellulose feeding bacteria was observed in the treatment with new fertilizer product "Agrobionov", which showed the 30.6% biological efficiency, apparently due to its carbon content.

Fly ashes are feeding ground for soil microorganisms due to their enriched content with macro and micronutrients.

TABLE I: Effect of Industrial Waste on Microbial Activity in the Common Chernozem Soil, %

Experimental treatments	Decomposition of linen cloth		Average in two years (2014-2015)
	Effect 2014	Residual effect 2015	
Control	12,5	10,1	11,3
P_{20}	34,9	21,5	28,2
Phosphogypsum 3 т/га	23,7	18,8	21,2
Fly ash 0.4 т/га	29,1	20,2	24,6
Agrobionov 0.4 т/га	37,2	24,1	30,6
Phosphate rock 0.3 т/га	28,3	17,2	22,7

In the treatments with fly ash in the rate of 0.4 t/ha and in the treatment with phosphogypsum in the rate of 3 t/ha, microbial activity was also higher compared to control by an average of 13.3% and 9.9% respectively.

The results of this experiment were confirmed by other experiments carried out abroad. Lee et al. (2009) revealed that the optimal rate of phosphogypsum significantly increased the soil microbial activity [15].

According to C.V. Mukhina, the application of phosphogypsum considerably increased the population size of actinomycetes (10.7%), cellulose decomposing bacteria (16.3%), and azotobacter. This is because phosphogypsum enhances soil enzyme activities (phosphatase and catalase activity), which leads to active fraction of soil organic matter [16].

According to the findings of Cerevelli (1986), Petruzzelli (1990), Wong (1986), the application of the fly ash showed a significant increase in soil aeration and soil enzymes activity [17-19].

Spring wheat is a highly demanding crop for mineral nutrients. Increased microbiological activity and organic acid production by soil bacteria enhance a degradation of silicate and increase a solubility of silicates and carbonates. This leads to an increase in availability of plant nutrients in soil. Table 2 illustrates the results of the analysis of easily hydrolysable nitrogen on common chernozem soil during the main stages of wheat development.

In 2014, before the sowing time of spring wheat, the content of easily hydrolysable nitrogen in the soil was medium. During tillering, i.e. the production of axillary shoots, a demand in plants for nitrogen increased, thereby reducing the soil content of easily hydrolysable nitrogen to the minimum level. Only when approaching to plant maturity stage the nutrient absorption from the soil gradually decreased, further it completely stopped. We also assume that the sharp increase in the total quantity of hydrolysable nitrogen in the period of full ripeness of spring wheat on all treatments of this experiment might be due to intense microbial activity.

TABLE II: EFFECT OF INDUSTRIAL WASTE ON THE CONTENT OF THE EASILY HYDROLYSABLE NITROGEN IN THE SOIL DEPTH OF 0-20 CM, MG/KG

Experimental treatments	2014			2015		
	Before sowing	Tillering	Before harvesting	Before sowing	Tillering	Before harvesting
Control	10,82	8,24	3,94	13,15	6,16	9,06
P_{20}	9,76	10,83	7,35	13,89	7,75	12,52
Phosphogypsum 3 т/га	10,35	8,44	6,23	12,43	8,71	11,14
Fly ash 0.4 т/га	10,12	9,51	6,81	12,55	5,87	9,87
Agrobionov 0.4 т/га	9,94	9,74	7,17	11,67	6,19	11,98
Phosphate rock 0.3 т/га	10,36	7,09	5,26	12,01	7,59	10,34

TABLE III: EFFECT OF INDUSTRIAL WASTE ON THE CONTENT OF ACTIVE PHOSPHORUS IN THE SOIL DEPTH OF 0-20 CM, MG/KG

Experimental treatments	2014			2015		
	Before sowing	Tillering	Full maturity	Before sowing	Tillering	Full maturity
Control	47,83	26,77	46,08	18,64	31,90	13,72
P_{20}	49,62	30,80	45,18	19,67	40,33	15,96
Phosphogypsum 3 т/га	50,13	31,14	45,64	19,62	34,15	20,44
Fly ash 0.4 т/га	48,97	30,46	46,12	20,85	31,92	21,56
Agrobionov 0.4 т/га	50,18	33,61	47,95	22,24	34,23	23,81
Phosphate rock 0.3 т/га	47,61	29,49	44,16	18,24	36,44	19,88

Therefore, the microbial activity increased because of the optimal air temperature in June and July and a humidity regime that was more than 3 times compared to previous years. Residual effect of applied industrial wastes positively influenced to the soil nitrogen regime. On average, all treatments showed the higher soil content of easily hydrolysable nitrogen of 15.5-25% compared to control treatment during the vegetative period of spring wheat. However, the highest efficiency was detected in the treatments with new fertilizer product "Agrobionov" in the rate of 0.4 t/ha and superphosphate in the rate of 20 kg/ha.

Saxena et al. (2005) showed improving of the soil nutrient regime and increasing the plant height of various vegetable crops during the application to the soil fly ash [20].

Phosphorus content in the soil is an important indicator of soil fertility in the conditions of North Kazakhstan. This is because of the fact that chernozem soil in the steppe zone has low content of active available phosphorus forms. The lack of phosphorus and moisture are the major limiting factors for crop yields.

According to the data shown in Table 3, the supply of active phosphorus in the topsoil (0-20 cm) was low. Due to the low level of phosphorus in the content of industrial wastes, there were not observed any noticeably increase in phosphorus mobilization. However, the increase in the P_2O_5 content was observed in the treatment with superphosphate.

On the other hand, it is worth to mention that the direct effect and residual effect of application of industrial wastes contributed to an increase of active phosphorus level to some extend compared to control.

Sarangi et al. (2001) showed that an application of fly ash not only increases content of active phosphorus, but also enhances soil reaction (pH), and soil organic carbon, as well as other soil organic matter [21].

Application of phosphogypsum at the rate of 3 t/ha does not cause an accumulation of heavy metals in the soil, whereas this rate increased content of the P_2O_5 to 5.6 mg/kg in the chernozem soil of the Kamennaya steppe [22].

Numerous international studies have been conducted to show the effectiveness of fly ash for cultivating grain crops, e.g. wheat (*Tritiucum aestivum*) [23], barley (Hordeum vulgare) [24].

Results of many studies confirmed that a phosphogypsum containing significant amounts of calcium, sulfur, and a number of microelements positively influenced to the soil quality and the development of spring wheat [25, 26].

Findings of current study illustrates that the application of industrial wastes improves the soil nutrient status and its microbial activity. Moreover, it has a complex effect on the yield of spring wheat (Table 4).

The highest efficiency among all treatments showed the application of the fertilizer product "Agrobionov" at the rate of 0.4 t/ha with an average yield 1.70 t/ha, which exceeds 0.31 t/ha or 21.4% yield compared to control. Application of phosphogypsum at the rate of 3 t/ha and fly ash at the rate of 0.4 t/ha also positively influenced to the wheat yield in both the year of application and the following year.

Due to soil drought in 2014, at the beginning of the growing season the phosphate rock composition did not dissolved in the soil solution and showed its efficiency only next year.

TABLE IV: EFFECT OF INDUSTRIAL WASTES ON THE YIELD OF THE SPRING WHEAT, T/HA

Experimental treatments	Effect In 2014	Residual effect in 2015	Average yield	Difference with Control	
				t/ha	%
Control	1,52	1,27	1,40	-	
P_{20}	1,94	1,59	1,77	0,37	26,4
Phosphogypsum 3 t/ha	1,83	1,50	1,67	0,27	19,2
Fly ash 0.4 t/ha	1,74	1,42	1,58	0,19	12,8
Agrobionov 0.4 t/ha	1,85	1,55	1,70	0,31	21,4
Phosphate rock 0.3 t/ha	1,28	1,57	1,43	0,03	2,1

Similar results were obtained in the experiment of Bana et al. (2015), which showed an efficiency of 7.5 % phosphogypsum on wheat that increased its yield up to 6.5 t/ha compared to control of 5.2 t/ha [27].

Residual effect of fly ashes application had a positive effect on yields of spring wheat according to studies of Singh & Singh (1986) [28].

IV. CONCLUSION

To sum up, among all treatments the new fertilizer product "Agrobionov" showed the highest efficiency on the soil microbial activity, nitrogen and phosphorus regime, wheat yield. Moreover, its efficiency rate was almost the same as widely used the superphosphates fertilizers. Furthermore, the application of fly ashes in the rate of 0.4 t/ha and the phosphogypsum in the rate of 3 t/ha allowed considerably increase wheat yield. This is also due to microbial activity that provides favorable conditions for uptake of nitrogen and phosphorous by plants during the vegetation plant growth. On the other hand, the efficiency of treatment with phosphate rock did not differ from control treatment. Therefore, the research results illustrates that an application of alternative types of fertilizers on spring wheat grown on the chernozem soil in the condititions of North Kazakhstan was effective and prospective method.

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