OnLine Journal of Biological Sciences

Original Research Paper

Effectiveness of the Use of Ash and Slag Fertilizer on Ordinary Chernozem for *Linum usitatissimum* Crops

Gulmira Kyzdarbekova, Abilzhan Khussainov, Baurzhan Yessenzholov, Sansyzbay Memeshov, Shynar Durmekbayeva, Anar Ayapbergenova and Gulzhan Dankina

Sh. Ualikhanov Kokshetau University, Kokshetau, Kazakhstan

Article history
Received: 05-12-2022
Revised: 16-02-2023
Accepted: 23-03-2023

Corresponding Author:
Gulmira Kyzdarbekova
Sh. Ualikhanov Kokshetau University, Kokshetau, Kazakhstan
Email: gulmira_80_01@mail.ru

Abstract: Degradation, reduction of soil fertility, and accumulation of industrial waste is both global and national environmental problem. The purpose of the study is to evaluate the effectiveness and environmental safety of the use of fertilizers made from ash and slag on ordinary chernozem for common flax (*Linum usitatissimum*) crops. The laboratory experiments were conducted in the environmental protection laboratory. The field experiments were conducted at the experimental field of Kokshetau University named after Sh. Ualikhanov in the period from 2018-2020. The content of heavy metals was determined by inversion voltammetry. It was found that the fertilizer made from ash and slag contributed to the improvement of edaphic factors. On average, over 3 years, the content of agronomically valuable aggregates increased to 65.9-73.2% (56.7% in the control variant) and the water resistance of soil aggregates increased by 7-29% compared to the control variant. The ecotoxicological assessment showed that the application of fertilizers in doses of 100-500 kg/ha on ordinary chernozem did not significantly affect the content of heavy metals in the soil compared to the control variant and also did not exceed the maximum permissible and approximately permissible concentrations. On fertilized variants, the increase in the yield of common flax grain averaged 0.09-0.34 t/ha, depending on the dose of application. The greatest increase in yield was obtained in the variant "background +300 kg/ha of fertilizer", which was 51.5% higher than in the control variant. In fertilized variants, a net income of $341.2 was received, which exceeded the control variant by $125/ha; thus the profitability was 257%. Studies have shown that the introduction of fertilizer from ash and slag into the soil in doses of 100-500 kg/ha is environmentally safe.

Keywords: Common Flax, Soil Structure, Water Resistance of Soil Aggregates, Yield, Heavy Metals

Introduction

The issues of soil degradation and dehumidification remain relevant all over the world, including in Kazakhstan. According to the United Nations (UN), degraded and arid soils occupy at least 30% of the earth's surface in more than 100 countries of the world, where about 2 billion people currently live (UN, 2020).

Degradation threatens the existence of 1 billion people in more than 100 countries, where about 12 million hectares of arable land are lost annually due to drought, which leads to a shortage of crops and a decrease in the provision of food to the population (Johnson and Lewis, 2007).

Human activities aimed at crop cultivation partially or completely change the biological cycle of substances, thereby disrupting the ability of the soil to self-regulate and reducing its fertility. Surface pollution, namely various pollutants, such as the use of various types of pesticides, mineral fertilizers, industrial waste emissions, and oil and petroleum products, also degrades soil properties, which, ultimately, can lead to soil dehumidification (Orr *et al*., 2017).

Therefore, the search for methods to prevent the development of soil degradation processes and the restoration of already degraded ones is extremely important for ensuring food security and environmental health and in general for global sustainable development.

The accumulation of ash and slag waste which has been stored in landfills for years is an acute problem in the Republic of Kazakhstan. The annual accumulation volume of this waste is 750 million tons (Ermagambet *et al*., 2020). In this regard, the most important field of environmental protection is the rational management of industrial waste disposal. The main role in this process is played by the economic stimulation of the introduction of environmentally friendly technologies for processing industrial waste to neutralize and dispose of it (Makhmetova, 2013). One of the ways to dispose of ash and slag waste is to use it as a fertilizer in crop cultivation. Ash and slag have great prospects for use in agriculture, due to their characteristics and ability to change the state of the soil and affect the productivity of crops due to the macro and microelements contained in their composition (PRK, 2016).

Kumar *et al*. (2017) note that ash and slag contain almost all plant nutrition elements and can be successfully used for fertilizing crops. At the same time, monitoring the content of heavy metals and radionuclides in soil and plants is an environmental requirement.

Ash and slag are environmentally friendly by nature, they are classified as non-hazardous waste. Currently, the use of Ash and Slag Materials (ASM) as a fertilizer to solve the problems of soil degradation and dehumidification is growing in popularity all over the world. Numerous studies on the use of ash and slag in various soil and climatic conditions prove that the use of ASM improves the physicochemical properties of the soil and the nutrient regime, increases the moisture-retaining ability of the soil, changes the acidity of the soil and acts as a melioration agent (Khan and Umar, 2019).

Usman *et al*. (2022) also think that due to the significant content of nutrients in ash and slag, soil fertility and plant growth can be improved. Evaluation of the structure, composition, and agrochemical properties of ash and slag waste showed the possibility of using them as soil fertilizer. The presence of nutrients (macro and microelements) and high porosity make ash and slag an excellent soil fertilizer to increase soil fertility and crop yields (Usman *et al*., 2022).

In connection with the above, the issues of solid waste disposal, in particular, ash and slag, are of great interest, both from an economic and environmental point of view (Navasardova *et al*., 2021). Firstly, they can ensure the improvement of the ecological situation in the areas of waste accumulation and secondly, the production and use of multi-component fertilizers will solve the problem of preserving and reproducing soil fertility, increasing the productivity of economically important food crops such as common flax (Khusainov *et al*., 2020b).

However, the results of studies by Ahmad *et al*. (2021) show that the introduction of ash and slag in a dose of 10-30% increased soil fertility, as well as the growth development and yield of crops. However, the introduction of higher doses of ash and slag (40 and 50%) showed a negative effect. That is, the effectiveness and environmental safety of the use of ash and slag depend on the doses of its application in specific natural and climatic conditions (Ahmad *et al*., 2021).

For the first time in the conditions of the steppe zone of Northern Kazakhstan, an ecological test of new ash and slag fertilizer was carried out on ordinary chernozem and common flax plants. We studied the effect of different doses of fertilizer on the edaphon of ordinary chernozem. The content of heavy metals in the soil was studied depending on different doses of fertilizer (Khusainov *et al*., 2020a).

The study aimed to develop environmentally safe and cost-effective methods of using fertilizers from ash and slag, ensuring the preservation of the fertility of ordinary chernozem and obtaining stable yields of common flax (*Linum usitatissimum*) of good quality in the conditions of Northern Kazakhstan.

To do that, the following objectives were set:

1. To study the influence of various doses of ash and slag fertilizer on the edaphic factors of ordinary chernozem
2. To conduct a comparative study of the effect of different doses of ash and slag fertilizer on the content of heavy metals in ordinary chernozem
3. To determine the influence of various doses of ash and slag fertilizer on the formation of the yield of common flax seeds
4. To determine the economic efficiency of using ash and slag fertilizers for common flax crops on ordinary chernozem

Materials and Methods

Location and Period of the Study

The study on the agroecological assessment of the use of carbon containing industrial waste for fertilizing chernozem soils on common flax crops was conducted from April to September 2018-2020 at the experimental field of the Elite educational research and production center at the Kokshetau University named after Sh. Ualikhanov at the Zerendinsky district of the Akmola region.

The experimental field was located 32 km north of the center of Kokshetau (coordinates: 53°10' 9.12 "N, 69°7' 37.57" E 53.1692°, 69.127103°).

Study Design

The soils were characterized by an average (lower bound) content of easily hydrolyzable nitrogen and mobile phosphorus and a high content of exchangeable potassium.

The element limiting crop yield in the conditions of ordinary chernozems of Northern Kazakhstan is phosphorus. Therefore, when choosing a scheme for conducting experiments with ash and slag fertilizer, a phosphorus fertilizer (granular double superphosphate; $Ca(H_2PO_4)$ was introduced as a background $2*N_2O$ with a phosphorus content of 42-46%).

The calculated dose of phosphorus fertilizers was set according to the formula (1) for the planned harvest of common flax:

$$Dp = 6 \times PY - 71 \times Ef \quad (1)$$

where, *D* is the dose, kg/ha; *PY* is the planned yield; *Ef* is the actual content of the element in the soil. On average, over three years, the estimated dose of phosphorus was 64 kg of the active material (a.m.)/ha.

The carbon containing ash and slag fertilizer was developed and produced from ash and slag obtained from the Ekibastuz Hydropower Plant (HPP) and technical carbon (waste from the Omsk tire plant at the agrobiotechnovation scientific and production association) in the proportion of 70% ash and slag and 30% technical carbon. The chemical composition of the fly ash of the Ekibastuz coal deposit was the following: C 30, SiO_2 44.03, Fe_2O_3 4.45, Al_2O_3 18.45, CaO 1.33, MgO 0.44, Na_2O 0.16, SO_3 0.84 and free calcium oxide 0.05%. Technical carbon consists of more than 99% carbon.

To study the environmental safety of the use of ash and slag fertilizers, a field experiment was established.

Experiment design:

1. Control (without fertilizer)
2. Background (1/10 of the calculated dose) P_2O_5: 6 kg/ha
3. Background + ash and slag fertilizers (100 kg/ha)
4. Background + ash and slag fertilizers (200 kg/ha)
5. Background + ash and slag fertilizers (300 kg/ha)
6. Background + ash and slag fertilizers (400 kg/ha)
7. Background + ash and slag fertilizers (500 kg/ha)

The experiments were performed in 4-fold repetition. The placement of variants in the experiment was systematic. The area of the experimental plot was 125 m^2 (5×25 m); the area of the accounting plot was 100 m^2 (4×25 m).

In the experiments, the Severnyi variety of common flax was used. The Severnyi variety has been zoned and approved for cultivation in Northern Kazakhstan since 2001. The variety is early maturing and the growing season equals 70-75 days.

Early in the spring, harrowing was carried out with a BIG-3 harrow. Ash and slag fertilizer was applied according to the experiment design. After fertilization, pre-sowing tilling was carried out to a depth of 8-10 cm with a KTSH-9 cultivator. Sowing was carried out with a Bistritsa seeder to a depth of 4-5 cm. The sowing rate of common flax was 35 kg/ha.

Sample Collection

The aggregate analysis of the soil was determined by the method of Savvinov. We determined the number of aggregates of different sizes in the range of 0.25-10 mm. An average sample of 0.5-2.5 kg was taken from soil samples. The average soil sample of 100 g was sifted through a set of sieves with a diameter of 10; 7; 5; 3; 2; 1; 0,5; 0,25 mm. After sifting the entire average sample, each fraction was weighed on techno chemical scales, and its content was calculated as a percentage of the mass of air-dry soil. The entire soil sample taken for analysis is taken as 100%. To assess the structural condition of the soil with a size of 0.25-10 mm, we used the following scale: Less than 20% is considered bad; 20-40% unsatisfactory; 40-60% satisfactory; 60-80% good; and more than 80% excellent.

Water Resistance

The water resistance of soil aggregates was determined with the method developed by Andrianov. The method is based on accounting for aggregates that have spread out in the water over a certain period. The aggregates of fractions from 1-2 mm were used for analysis. A piece of filter paper was placed on the bottom of the Petri dish and 40 lumps of soil were spread out in regular circles on it. Water was poured into the Petri dish until the filter paper sheet was completely moistened and after 3 min, when capillary saturation of the aggregates occurred, water at room temperature was carefully added to it so that it covered the aggregates with a layer of 0.5 cm. Within 10 min, completely disintegrated aggregates were counted every minute. The water resistance of lumps that had not spread out within 10 min was taken as 100%. To assess the water resistance of soil with a size of 1-2 mm, we used the following scale: The result of less than 10% was considered not water resistant; the water resistance of 10-20% was considered unsatisfactory; of 20-30% insufficiently satisfactory; of 30-40% satisfactory; of 40-60% good; of 60-75% excellent; and more than 75% excessive.

Content of Heavy Metals

The content of heavy metals in the soil was determined by the device of the atomic absorption spectrophotometer Spectr AA 50B made by Agilent technologies, Inc. (USA). Technical characteristics of the device: Spectrum range: 185-650 nm, sensitivity: Cu 0.45, Zn 50, Pb 0.85, Cd 0.01 micrograms/dm^3, deviation: 2-5%. Concentrations of heavy metals in common flax seeds were determined by the method of flame atomic absorption. The content of heavy metals in the soil was determined by inversion voltammetry.

Economic Efficiency

The economic efficiency of the use of ash and slag fertilizers was calculated according to the following main

DOI: 10.3844/ojbsci.2023.276.285

indicators: The level of yield, direct costs, production cost, production prime cost, net income, and the level of profitability of the oilseed cultivation.

The production value was calculated by multiplying the yield of the purchase price. The prime cost of one ton shows the cost of obtaining one ton of flax, which was calculated by dividing the sum of all costs for yield. To obtain a net income, the costs were subtracted from the production value (Kovalenko, 2022):

$$Profitability\% = \frac{net\,income}{cost} \times 100\% \quad (2)$$

Statistical Analysis

Crop accounting and statistical processing of crop data were carried out according to the Least Significant Difference (LSD). Statistica13.5 software was used for calculations.

Results

Effect of Doses of Ash and Slag Fertilizer on the Structure of Ordinary Chernozem

We present the results of studies of aggregate soil analysis in the experiment with the use of increasing doses of ash and slag fertilizer against the background of the calculated norms of phosphorus fertilizers. In all fertilized variants, in comparison with the control one, we noted a decrease in the proportion of large aggregates larger than 10 mm in the 0-20 soil layer from 29.46% (max) registered in the variant with the introduction of 1/10 of the calculated rate of phosphorus fertilizers to 20.06% (min) registered in the variant with the introduction of 300 kg/ha of ash and slag fertilizer against a 1/10 background (Fig. 1).

In the control variant, this indicator in the 0-20 cm layer was 34.33%.

Along with a decrease in the proportion of large aggregates over 10 mm, there was an increase in the content of agronomically valuable soil aggregates (0.25-10 mm). In the upper layer of the soil from 61.9% in the 1/10 P_6 background variant, the maximum value was up to 73.2%; in the background +300 kg/ha variant, the minimum value was registered. In the control variant, this indicator was 56.7%. The positive effect of ash and slag fertilizer on the soil structure was evidenced by a decrease in the content of silt with a size of <0.1 mm.

Depending on the dose of ash and slag fertilizer, it varied from 0.9% in the control variant to 0.2-0.5% in the fertilized variants.

According to the scale, in the fertilized variants, the aggregate state of the soils improved from satisfactory (60-40%) in the control one to good (80-60%) in the fertilized variants.

The optimal ratio of agronomically valuable soil aggregates in a layer of 0-20 cm was noted in the variant with the introduction of 300 kg/ha of ash and slag fertilizer against the background of phosphorus fertilizers (73.2%).

Figure 1, in the case of the use of ash and slag fertilizer, the proportion of large aggregates larger than 10 mm in size decreased to 20.06% with the introduction of 300 kg/ha of ash and slag fertilizer. A further increase in the dose by 100 and 200 kg, on the contrary, increased the number of aggregates larger than 10 mm. The share of aggregates in the variant where 200 kg/ha of ash and slag fertilizers were used equaled 14.25%, while in the control variant, it was 12.9%.

The percentage ratio of aggregates with a size of 2-5 mm increased maximally in the variant with 500 kg/ha of ash and slag fertilizers against the background of phosphorus fertilizers (12.71%), while in the control variant, this value equaled 9.75%.

Water Resistance of Soil Aggregates Depending on the Application of Ash and Slag Fertilizer

According to the results obtained when studying the effect of increasing doses of ash and slag fertilizer against the background of phosphorus fertilizers, the water resistance of soil aggregates in the 0-20 cm soil layer of the fertilized variants was 44-70% in 2018, 50-60% in 2019, 55-64% in 2020, while it equaled 38, 34 and 36%, respectively, in the control variant (Fig. 2).

The results of our studies show satisfactory water resistance in the control variant (30-40%), while in the fertilized variants the water resistance was good (40-60%) and excellent (60-75%).

The maximum effect was obtained on the variant of background +300 kg/ha ash and slag fertilizers, where the water resistance of soil aggregates averaged 65% over 3 years, which is characterized as an excellent indicator.

Thus, our study on the use of various doses of ash and slag fertilizer had a positive effect on increasing the water resistance of soil aggregates from 7-29%, depending on the variant of the experiment, which increased the resistance of soils to the effects of degradation processes.

Effect of Doses of Ash and Slag Fertilizer on the Content of Heavy Metals in Ordinary Chernozem

Studies on the environmental assessment of the doses of ash and slag fertilizer against the background of the calculated rate of phosphorus fertilizers according to the experimental variants, a slight increase in the lead content in the soil from 5.07-5.77 mg/kg was noted in comparison with the control 4.78 mg/kg (Table 1).

The level of cadmium accumulation in the soil varies within the values of the control variant of 0.10-0.14 mg/kg (with 0.10 mg/kg in the control variant). With an increase in the dose of ash and slag fertilizer, the accumulation of copper in the soil decreased from 3.63-4.40 mg/kg (4.41 mg/kg in the control variant).

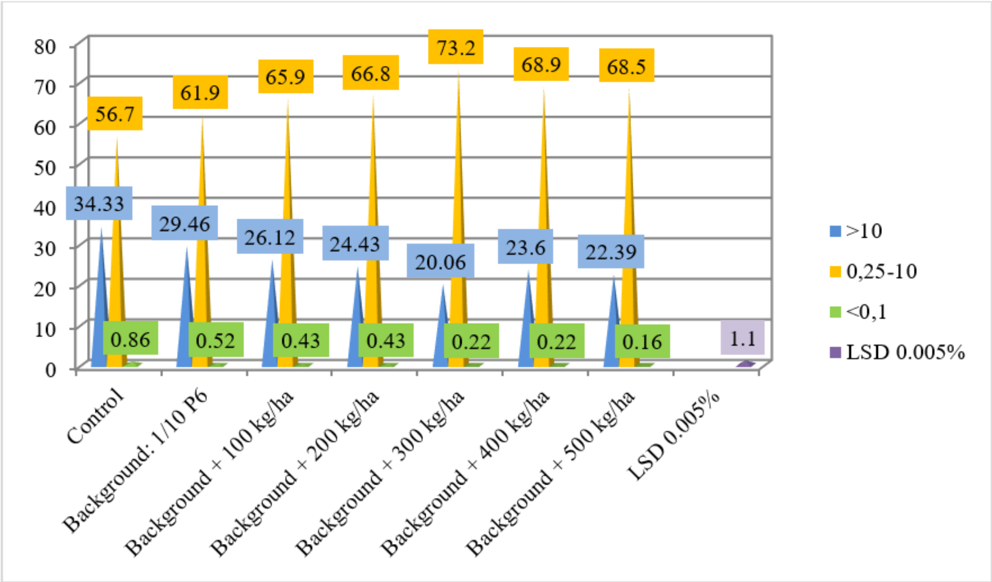

Fig. 1: The effect of doses of ash and slag fertilizer on the structure of ordinary chernozem, % (average for 2018-2020)

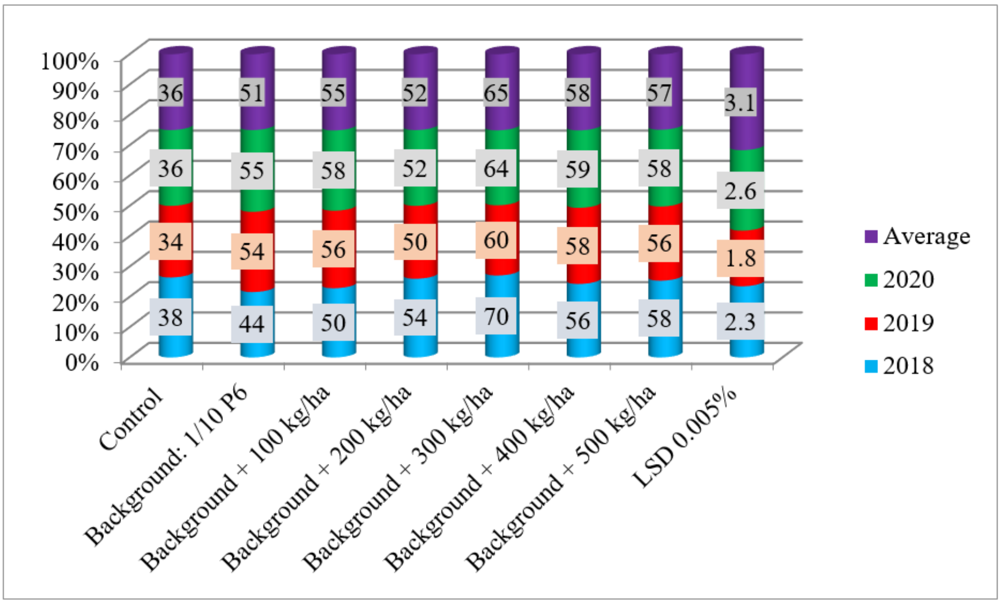

Fig. 2: The water resistance of soil aggregates of ordinary chernozem, depending on the doses of ash and slag fertilizer application under the crops of common flax, % (average for 2018-2020)

Table 1: The effect of doses of ash and slag fertilizer on the content of heavy metals in ordinary chernozem, mg/kg (average for 2018-2020)

Variant	Pb	Cd	Cu	Zn
Control	4.78	0.10	4.41	19.27
Background: 1/10 P_6	5.07	0.14	4.40	12.45
Background + ash and slag fertilizers (100 kg/ha)	4.75	0.10	3.63	10.29
Background +300 kg/ha	5.74	0.11	3.87	11.61
Background + ash and slag fertilizers (500 kg/ha)	5.77	0.10	4.27	13.17
Maximal Allowable Concentration (MAC)	32.00	1.00	-	-
Approximate Allowable Concentration (AAC)			33.00	55.00

DOI: 10.3844/ojbsci.2023.276.285

The zinc content in the soil in the fertilized variants was 6.10-8.98 mg/kg lower than in the control variant (19.27 mg/kg).

The content of heavy metals in the soil did not exceed the MAC and the AAC.

The amount of accumulated lead was greater in the variants with the introduction of ash and slag fertilizer, whereas for other elements their greater accumulation was noted in the variant with only phosphorus fertilizers and the control variant.

The results of our study on the use of various doses of ash and slag fertilizer show the environmental safety of using this fertilizer on ordinary chernozem for common flax crops.

Effect of Doses of Ash and Slag Fertilizer on the Yield of Common Flax Seeds

The yield of common flax in our studies varied depending on both weather and climatic conditions and different doses of application of ash and slag fertilizer in 2018 and 2020. The fertilized variants showed an increase in the yield of common flax, depending on the dose of ash and slag fertilizer, by 0.10-0.35 t/ha (Table 2). The greatest increase in yield was obtained on the variant with the introduction of 300 kg/ha of ash and slag fertilizer against the background of phosphorus fertilizers, equaling 1.12 t/ha, which was higher than the control variant by 0.35 t/ha.

In the arid conditions of 2019, the yield of flax oilseeds in the control variant was 0.57 t/ha. Despite the drought, the application of fertilizers was effective due to the improvement of the conditions of the moisture supply of plants during the growing season (according to the reserves of productive moisture). The yield of common flax increased from 0.64 t/ha-0.90 t/ha with a maximum value in the variant with the introduction of 300 kg/ha of ash and slag fertilizer. The yield value was higher than the control variant by 0.33 t/ha.

In 2020, also with a lack of precipitation during the growing season, the yield of common flax in the fertilized variants was 0.98 and 0.71 t/ha, exceeding the control variant by 0.07-0.34 t/ha. The highest yield of oilseeds was obtained on variants with doses of ash and slag fertilizer from 300-500 kg /ha, where the yield equaled 0.98 and 0.95 t/ha, respectively.

On average, for three years in the fertilized variants, the increase in the yield of common flax grain, depending on the dose of application, amounted to 0.09-0.34 t/ha. The greatest increase in yield was obtained on the background +300 kg/ha variant, equaling 0.34 t/ha, which was 51.5% higher than the control variant.

Table 2: Effect of doses of ash and slag fertilizer on the yield of common flax seeds, t/ha

Variant	Yield, t/ha				Increase compared to the control variant	
	2018	2019	2020	Average	Yield, t/ha	(%)
Control (without fertilizers)	0.77	0.57	0.64	0.66	-	-
Background: 1/10 P_6	0.91	0.64	0.71	0.75	0.14	21.2
Background +100 kg/ha ash and slag fertilizers	0.87	0.66	0.71	0.75	0.09	13.6
Background +200 kg/ha	0.98	0.74	0.81	0.84	0.18	27.3
Background +300 kg/ha	1.12	0.90	0.98	1.00	0.34	51.5
Background +400 kg/ha	1.00	0.85	0.98	0.94	0.28	42.4
Background +500 kg/ha ash and slag fertilizers	1.08	0.83	0.95	0.95	0.29	43.9
The precision of the experiment, %	1.84	4.38	2.02	2.75	-	-
LSD $_{0.95}$	0.04	0.07	0.03	0.04	-	-

Table 3: Economic efficiency of using different doses of ash and slag fertilizer on common flax crops (average for 2018-2020)

Experiment variant	Yield, t/ha	Direct costs, $/ha	Cost of production from1 ha, $	Prime production cost 1 ton, $	Net income from 1 ha, t$	Profitability level, %
Control	0.66	96.500	312.8	146.2	216.3	224
Background: 1/10 P_6	0.75	1046.6	355.4	139.6	250.7	240
Background + ash and slag fertilizers 100 kg/ha	0.75	114.00	355.4	152.0	241,4$	212
Background +200 kg/ha	0.84	123.30	398.1	146.8	274.7	223
Background +300 kg/ha	1.00	132.70	473.9	132.7	341.2	257
Background +400 kg/ha	0.94	142.00	445.5	151.0	303.5	214
Background + ash and slag fertilizers (500 kg/ha)	0.95	151.30	450.2	159.3	299.0	198

Economic Efficiency of Using Ash and Slag Fertilizers on Common Flax Crops

We also established the economic efficiency of using ash and slag fertilizers in combination with phosphorus fertilizers. According to our calculations, the net income in the control variant was $216.3 and in the fertilized variants, the net income was higher, even though the additional costs associated with the purchase of phosphorus fertilizers and ash and slag fertilizers ranged from $8.2-$54.8 (Table 3).

The greatest net income was received in the variant with background +300 kg/ha of ash and slag fertilizers, on average equaling $341.2, which exceeded the control variant by $125/ha. The level of profitability in the control variant was 224% and in the fertilized variants, a high profitability indicator compared to the control variant was shown by the following ones: 1/10 P_6 (background) had profitability of 240%, and the background +300 kg/ha of ash and slag fertilizer 257%.

Discussion

Soil fertility largely depends on the aggregate composition of particles, water retention capacity, water permeability, and other soil indicators. The main reasons for the deterioration of the agrophysical properties of the arable layer and the compaction of the sub-arable horizon are the impact of agricultural machinery during tillage and harvesting of crops. The increased anthropogenic load on chernozems has led to changes in morphological, agrochemical, hydrophysical properties and other factors of fertility decline. The hydrophysical properties of the soil have a great influence on soil formation processes and largely determine soil fertility, which, in turn, affects crop yields (Bochkarev *et al*., 2017; Kantarbayeva *et al*., 2017).

There is insufficient data in the academic literature on the use of ash and slag fertilizers on chernozem soils. Therefore, we consider it important to study ash and slag fertilizers on chernozem soils, as this increases yields.

Paleev and Khudyakova (2021) showed that ash and slag waste can be widely used in agriculture as mineral fertilizers, and micro fertilizers, as well as for soil remediation and land reclamation. The use of ash and slag waste in agriculture will reduce the environmental burden on the environment, as well as prevent further waste storage and make possible further processing (Paleev and Khudyakova, 2021). We agree with these conclusions. A sufficient amount of ash and slag waste has accumulated in the Akmola region. Its use as a fertilizer will provide the soil with the necessary nutrients, as well as solve the problem of processing and disposal of ash and slag waste.

Huang *et al*. (2011) note that the addition of moderate amounts of ash and slag to the arable soil layer increases productivity and reproduces soil fertility while reducing the amount of waste accumulation in landfills. The use of ash and slag as a melioration agent and fertilizer, due to the high content of several elements (K, Na, Zn, Ca, Mg, and Fe), improves the agrophysical properties of the soil, enriches it with macro and microelements and increases crop yields. In our studies, the use of ash and slag on chernozem soils for common flax crops at a dose of 300 kg/ha increased yield by 51% compared to the control variant. Thus, the obtained data show that ash and slag have a positive effect on the aggregate composition, water resistance of soil aggregates, and yield.

Rajakumar and Patil (2019) claim that the use of ash and slag on chernozem soil at the rate of 30 t/ha improves the growth and yield of oilseeds (sunflower). Based on our study, the use of ash and slag at a dose of 30 t/ha and 300 kg/ha shows the same result. However, the use of ash and slag in smaller quantities is economically profitable and environmentally safe.

Antonkiewicz *et al*. (2014) note that in the variants where ash and slag were used, the content of heavy metals did not exceed the MAC.

Studies by Khusainov *et al*. (2020b) have shown that the introduction of preparation from ash and technical carbon on chernozem soils in doses of 100-500 kg/ha for common flax crops is environmentally safe.

Khusainov *et al*. (2020a) indicate that the use of ash and slag fertilizers and technical coal is environmentally safe, the content of heavy metals and radionuclides does not exceed the MAC and it also improves the biological properties of the soil, contributes to an increase in the number of ammonifying bacteria acting as nitrifiers in the soil on spring wheat crops.

Jala and Goyal (2006), in their studies on the use of Ground Fly Ash (GFA), note a positive trend in improving the physico chemical properties of the soil: An increase in the water-holding capacity of the soil and moisture content by 2.85-4.43%.

Our study also confirms the beneficial effect of ash and slag on the hydrophysical properties of the soil. In particular, the soil structure improved by 5.2-16.5% and the water resistance of soil aggregates improved by 15-29% on ordinary chernozem under common flax crops.

The most agronomically valuable aggregates are soil micro aggregates with a size of 0.25-1.0 mm. Structural soil is considered to be the soil in which the content of these valuable water-resistant micro aggregates (with dimensions of 0.25-1.0 mm) is at least 55% (Kovrigo *et al*., 2000).

Kotelnikova *et al*. (2022) confirm that the introduction of ash and slag into sod podzolic soil at a ratio of ash to the soil of 1:2 or 1:5 of ash and slag can aggregate with soil particles, forming agrophysically valuable aggregates of 250-2000 microns in size. Our study also shows that the introduction of ash and slag in doses of 100-500 kg/ha increases the content of agrophysically valuable aggregates with a size of 0.25-10 mm.

The use of ash and slag fertilizer does not change the natural radioactivity of the soil, but, on the contrary, the use of various doses of ash and slag fertilizer slightly reduces the content of heavy metals. Thus, at the optimal dose of ash and slag of 60 t/ha, there was a decrease in the lead by 2 times (130.0 mg/kg), copper by 8 times (132.0 mg/kg), zinc by 5-7 times (220.0 mg/kg) and cadmium by 8 times (2.0 mg/kg) (Grebenshchikova, 2007).

Panda *et al*. (2021) assert that the use of ash and slag in a dose of 25% as a soil fertilizer when growing *B. monnieri*. L. leads to an increase in plant biomass and essential oil. However, these parameters were significantly reduced when the soil was treated with higher doses of ash and slag.

During the study, our conclusions on the use of ash and slag fertilizer at a dose of 300 kg/ha increased the yield by 13.6-51.5%. With the maximum use of ash and slag at a dose of 500 kg/ha, a decrease in all the indicators studied by us was not observed in comparison with the control variants.

Conclusion

It was found that the ash and slag fertilizer contributed to the improvement of edaphic factors. On average, over 3 years, the content of agronomically valuable aggregates increased to 65.9-73.2% (56.7% in the control variant) and the water resistance of soil aggregates increased by 7-29% compared to the control variant.

The ecotoxicological assessment showed that the application of ash and slag fertilizer in doses of 100-500 kg/ha on ordinary chernozem did not significantly affect the content of heavy metals in the soil. Changes were noted in the content of heavy metals: The lead content was 4.75-5.77 mg/ha (4.78 mg/kg in the control variant); cadmium content was 0.10-0.14 mg/kg (0.10 mg/kg in the control variant); copper content was 3.63-4.40 mg/kg (4.41 mg/kg in the control variant); zinc content was 10.29-13.17 mg/kg (19.27 mg/kg in the control variant). In general, the content of heavy metals did not exceed the MAC and the AAC.

On average, for three years in the fertilized variants, the increase in the yield of common flax grain, depending on the dose of application, amounted to 0.09-0.34 t/ha. The greatest increase in yield was obtained on the variant with the background +300 kg/ha of ash and slag fertilizers (0.34 t/ha), which was 51.5% higher than the control variant. The largest net income was obtained on the variant with the background +300 kg/ha of ash and slag fertilizer ($341.2), which exceeds the control variant by $125/ha; the profitability amounted to 257%.

The studied fertilizer has a powdery shape, which complicates its use in production. To commercialize and scale this product, there is a need to granulate this fertilizer. Further research is needed on ash and slag fertilizers for crops of various oilseeds, soybeans, corn, sunflower, and rapeseed, in the arid conditions of Kazakhstan.

Acknowledgment

The authors thank the reviewers for their contribution to the peer evaluation of this study.

Funding Information

The authors have not received any financial support or funding to report.

Author's Contributions

All authors equally contributed in this study.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues are involved.

References

Ahmad, G., Khan, A. A., & Mohamed, H. I. (2021). Impact of the low and high concentrations of fly ash amended soil on growth, a physiological response and yield of pumpkin (*Cucurbita moschata Duch. Ex Poiret* L.). *Environmental Science and Pollution Research*, *28*, 17068-17083. https://doi.org/10.1007/s11356-020-12029-8

Antonkiewicz, J., Pelka, R., & Kowalewska, A. (2014). Fractions of heavy metals in the soil after the application of municipal sewage sludge, peat and furnace ash. *Toprak Su Dergisi*, 29-35. https://dergipark.org.tr/en/pub/topraksu/issue/21418/229579

Bochkarev, D.V., T.F. Devyatkina, Yu.N. Nedaiborsch, S.V. Emelyanov and V.D. Bochkarev. (2017). Influence of Development Methods of fallow Lands on Agrophysical Indicators of Fertility of Podzolic Chernozem. *Agrarnyi Nauchnyi Zhurnal*, *11*, 6-10. https://www.agrojr.ru/index.php/asj/article/view/221

Ermagambet, B.T., N.U. Nurgaliev, Zh.M. Kasenova, R.K. Urlibai, O.S. Bolat and Ya.A. Semenova, (2020). Ash and Slag Waste Processing Technology of Kazakhstan. http://nur.nu.edu.kz/handle/123456789/4942

Grebenshchikova, E.A. (2007). Vliyanie zoloshlaka na svoistva pochv i soderzhanie tyazhelykh metallov pri ispolzovanii ego v kachestve melioranta [Influence of ash and slag on soil properties and content of heavy metals when used as an ameliorant]. A cand. biol. sci. dissertation: 03.00.27, Institute of Biology and Soil of the Far Eastern Branch of the Russian Academy of Sciences, Blagoveshchensk, Russia, pp: 132. https://www.dissercat.com/content/vliyanie-zoloshlaka-na-svoistva-pochv-i-soderzhanie-tyazhelykh-metallov-pri-ispolzovanii-ego

Huang, P. M., Li, Y., & Sumner, M. E. (Eds.). (2011). *Handbook of soil sciences: Resource management and environmental impacts*. CRC Press. ISBN-10: 9781439803080.

Jala, S., & Goyal, D. (2006). Fly ash as a soil ameliorant for improving crop production-a review. *Bioresource Technology*, *97*(9), 1136-1147. https://doi.org/10.1016/j.biortech.2004.09.004

Johnson, D. L., & Lewis, L. A. (2007). *Land degradation: Creation and destruction*. Rowman & Littlefield. ISBN-10: 9780742519480.

Kantarbayeva, E. E., Shayakhmetova, A. S., Koshen, B. M., & Zholamanov, K. K. (2017). The density of planting and the productivity of corn in the context of forest-steppe zone of Northern Kazakhstan. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences, 19*(1), 2017, 116-120. http://www.envirobiotechjournals.com/article_abstract.php?aid=7726&iid=227&jid=1

Khan, I., & Umar, R. (2019). Environmental risk assessment of coal fly ash on soil and groundwater quality, Aligarh, India. *Groundwater for Sustainable Development*, *8*, 346-357. https://doi.org/10.1016/j.gsd.2018.12.002

Khusainov, A., Yessenzholov, B., Zharkinbekov, T., Sarsenova, A., & Sindireva, A. (2020a). Ecological rationing of doses of a multicomponent carboncontaining preparation through heavy metal content and soil microbiological activity. *Periodico Tche Quimica*, *17*(34), 425-435. https://doi.org/10.52571/ptq.v17.n34.2020.449_p34_pgs_425_435.pdf

Khusainov, A., Skipin, L., Kyzdarbekova, G., Khusainova, R., & Kakabaev, A. (2020b). The Sprouting Activity of Oil Flax Seeds after Treatment with a Preparation Made of Bottom Ash and Technical Carbon. *Journal of Ecological Engineering*, *21*(3). https://doi.org/ 10.12911/22998993/118279

Kotelnikova, A. D., Rogova, O. B., Karpukhina, E. A., Solopov, A. B., Levin, I. S., Levkina, V. V., ... & Volkov, D. S. (2022). Assessment of the structure, composition and agrochemical properties of fly ash and ash-and-slug waste from coal-fired power plants for their possible use as soil ameliorants. *Journal of Cleaner Production*, *333*, 130088. https://doi.org/10.1016/j.jclepro.2021.130088

Kovalenko, N., Ya. (Ed.). (2022). Ekonomika selskogo khozyaistva: Uchebnik dlya vuzov [Agricultural economics: A textbook for universities]. Izdatelstvo Yurait, Moscow. pp: 406. ISBN-10: 9785991687690.

Kovrigo, V. P., Kaurichev, I. S., & Burlakova, L. M. (2000). Edaphology with the basics of geology. *Moscow*. p: 416. http://www.booksshare.net/books/geology/kovrigovp/2000/files/pochvoved_osngeol.pdf

Makhmetova, L. (2013). Production and consumption waste management: Legislation of the Republic of Kazakhstan, practice of its application and development prospects. In: *XI International Atyrau Legal Conference "Topical issues and analysis of the practice of applying legislation in the oil and gas industry of the Republic of Kazakhstan".* Atyrau, Kazakhstan, pp: 9-15. https://online.zakon.kz/Document/?doc_id=31480694&pos=35;105#pos=35;105

Navasardova, E. S., Zaharin, A. N., Kolesnikova, K. V., Nutrikhin, R. V., & Shinkarev, V. A. (2021). Regulation of waste management and elimination of accumulated damage in the countries of the Eurasian economic union. *Journal of Environmental Management and Tourism*, *12*(7), 1826-37. https://www.ceeol.com/search/article-detail?id=1023077

Orr, B. J., Cowie, A. L., Castillo Sanchez, V. M., Chasek, P., Crossman, N. D., Erlewein, A., ... & Welton, S. (2017). Scientific conceptual framework for land degradation neutrality. In *A report of the science-policy interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany* (pp. 1-98). https://www.unccd.int/sites/default/files/2018-09/LDN_CF_report_web-english.pdf

Paleev, P.L., & Khudyakova L.I. (2021). Applications of ash and slag waste in agriculture. XXI Century. Technosphere Safety, 6 (4): 348-356. [In Russ.]. https://doi.org/10.21285/2500-1582-2021-4-348-356

Panda, D., Barik, J. R., Barik, J., Behera, P. K., & Dash, D. (2021). Suitability of Brahmi (*Bacopa monnieri* L.) cultivation on fly ash-amended soil for better growth and oil content. *International Journal of Phytoremediation*, *23*(1), 72-79. https://doi.org/10.1080/15226514.2020.1791052

PRK. (2016). On the introduction of amendments and additions to some legislative acts of the Republic of Kazakhstan on the issues of the transition of the Republic of Kazakhstan to a "green economy" https://adilet.zan.kz/rus/docs/Z1600000506

Rajakumar, G. R., & Patil, S. V. (2019). Effect of fly ash on growth and yield of crops with special emphasis on heavy metals and radionuclides. *Int J Curr Microbiol App Sci*, *8*(8), 127-137. http://dx.doi.org/10.20546/ijcmas.2019.808.016

Kumar, T., Tedia, K., Samadhiya, V., & Kumar, R. (2017). Review on effect of fly ash on heavy metals status of soil and plants. *Int J Chem Stud*, *5*(4), 11-18. https://www.chemijournal.com/archives/2017/vol5issue4/PartA/5-3-116-148.pdf

Usman, M., Anastopoulos, I., Hamid, Y., & Wakeel, A. (2022). Recent trends in the use of fly ash for the adsorption of pollutants in contaminated wastewater and soils: Effects on soil quality and plant growth. *Environmental Science and Pollution Research*, 1-20. https://doi.org/10.1007/s11356-022-19192-0

UN. (2020). Statisticheskaya komissiya: Doklad o rabote pyatdesyat pervoi [Statistical commission: Report on the work of the fifty-first commission]. https://unstats.un.org/unsd/statcom/51st-session/documents/2020-37-FinalReport-R.pdf