Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Cultivation of irrigated crops in the application of biochar technology in the Southeast Kazakhstan

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ABSTRACT
Based on the establishment and field experiments in two agroecological zones of southeastern Kazakhstan, optimal methods, doses, and ratios of applying biochar to the main irrigated crops have been developed, and the features of their growth and development, crop formation, and product quality have been studied. Introducing biochar in doses of 15-20 tons ha^{-1} for basic tillage helps to improve the bulk weight and increases the content of agronomically valuable and durable aggregates of the arable soil layer.

Keywords: Biochar, Irrigation, Rice, Soybeans, Spring wheat, Degraded soil, Yield.
Article type: Research Article.

INTRODUCTION
Currently, Kazakhstan is facing serious deterioration of the state of natural resources and the environment in all the most important environmental indicators. Almost a third of agricultural land is now degraded or under serious threat, and more than 10 million hectares of potentially arable land have been abandoned in the past (How the area of irrigated lands is being increased in the Republic of Kazakhstan 2020, Paramonov 2009). The annual monitoring of irrigated lands conducted by hydrogeological and reclamation expeditions shows that more than 50% of irrigated lands currently have varying degrees of salinity, and more than 30% are brackish. At the same time, huge volumes of drainage and wastewater generated on irrigated lands and in settlements (up to 10-30%) pollute water sources and worsen the ecological and reclamation situation of irrigated lands and adjacent territories. In general, over the period of 1990-2012, the area of irrigated land in the country decreased from 2.5 to 2.1 million ha, of which no more than 1.4 million hectares are currently used. Over 100,000 hectares of irrigated land have been withdrawn from agricultural circulation (Kvan *et al.* 2011). Biochar is a biofertilizer and a unique soil restorer. The composition of the biochar mainly includes carbon accumulated by burned plants. Biochar is used as an organic fertilizer capable of preserving water and nutrients in the soil, dramatically increasing soil fertility and agricultural productivity. The cultivation of the land for many centuries has led to a deterioration in its quality; the earth's ability to quickly absorb water has deteriorated. The development of biochar production and application in agriculture and forestry makes it possible to improve land fertility in a short time. Today, biochar is one of the most promising types of fertilizer because when fertilizing the soil, new plants grow and develop well, and this type of fertilizer does not pollute the atmosphere with carbon dioxide. Many scientists call biochar "black gold" for farming. Studies on Biochar in Kazakhstan are isolated. They mainly concern studies on the rehabilitation of soils contaminated with heavy metals by mining and metallurgical enterprises of the city of Ridder in the East Kazakhstan region (Kozybaeva *et al.* 2014). The study's results on fertile dark chestnut soils

Caspian Journal of Environmental Sciences, Vol. 23 No. 2 pp. 425-435 Received: May. 08, 2024 Revised: Sep. 14, 2024 Accepted: Oct. 27, 2024
DOI: 10.22124/CJES.2025.8757

Publisher: University of Guilan,

showed a relatively high efficiency in applying Biochar for vegetable crops (Sarkulova 2019). Some publications related to the review of the literature of foreign authors on the study of Biochar (Kerimkulova *et al.* 2017). However, so far, no targeted studies have been conducted to study the effectiveness of Biochar for the main field crops of the irrigated zone of Kazakhstan, its reclamation qualities for the restoration of degraded infertile lands in the south and south-east of Kazakhstan, in particular ordinary gray soils with a close occurrence of pebbles, so-called soils, which are characterized by a very low content of organic matter (less than 1%). The role of Biochar in changing the degree of greenhouse gas emissions and mitigating the effects of climate change has not been identified. The task of producing more food for a growing global population while mitigating the effects of climate change requires new solutions for managing agricultural systems (Smith *et al.* 2013). Biochar in soil has received increasing attention as an alternative method for increasing long-term soil carbon levels while potentially improving soil quality and crop yields (Lehmann *et al.* 2006). Biochar is the term given to charcoal or carbonized biomass when it is used to sequester carbon in the soil and increase soil fertility (O'Toole *et al.* 2016). Meta-analyses confirm that Biochar can improve the physical and hydrological functioning of the soil (Omondi *et al.* 2016) and can reduce N_2O and CH_4 emissions (Cayuela *et al.* 2014; Jeffery *et al.* 2016). Numerous studies have shown that Biochar increases crop yields by an average of 25% in the tropics but has no effect in temperate regions (Jeffery *et al.* 2017). In Norway, the use of Biochar is recognized as one of several methods that can significantly reduce the carbon footprint of the agricultural sector (Strategy and Incentives for Reducing Emissions of GHGs from the Agricultural Sector 2010; Rasse *et al.* 2017). Previous agronomic studies of Biochar have shown enhancing water retention (Peake *et al.* 2014; Sun *et al.* 2014), which is often explained by the large surface area and internal porosity of the Biochar as well as its ability to change the interporous porosity between particles of mineral soil (Liu *et al.* 2017). It has been shown that Biochar simultaneously increases saturated hydraulic conductivity (Ksat) in clay soil and reduces it in sandy soil (Barnes *et al.* 2014; Lim *et al.* 2016) due to either filling pore spaces in sand or opening pore channels in clay (Masiello *et al.* 2015). However, the results of studies on the effect of Biochar on K sat vary widely depending on the soil, the type of Biochar used, and the rate of correction (Obia *et al.* 2016). A number of studies have noted an improvement in the soil structure, which is manifested in an increase in aggregate stability (Busscher *et al.* 2010; Herath *et al.* 2013; Liu *et al.* 2017) and a drop in penetration resistance (pr; Obia *et al.* 2017; Ahmed *et al.* 2017). Again, the mechanisms involved depend on the interaction between biochar and soil properties. In clay soils, it has been shown that Biochar reduces the tensile strength of the soil and the plasticity index (degree of swelling/shrinkage), but usually requires high application speeds (Chan *et al.* 2008; Zong *et al.* 2014). The relationship between the properties of Biochar and its function as a soil improver is well illustrated by the relationship between the moisture retention capacity of soils and the porosity of Biochar. Some studies, for example Karhu *et al.* (2011) suggested that the increased porosity of the Biochar elevates water retention in soils, depending on the feedstock of the Biochar, soil type, and mixing rate. Nutrients dissolved in water can be preserved in the soil and, therefore, be available to plants (Yu *et al.* 2013). The Biochar's ability to increase water retention capacity will have profound consequences for drought-prone areas (Zhang *et al.* 2013). Other studies positively associate using Biochar with increased soil moisture retention capacity (Kinney *et al.* 2012; Akhtar *et al.* 2014; Gray *et al.* 2014), which leads to increased crop yields due to increased soil moisture in conditions of reduced irrigation regimes. The European Union recognizes biochar as a valid long-term soil carbon storage technology. Therefore it is aimed at mitigating the effects of climate change (Lehmann *et al.* 2019). In addition, using Biochar as a soil amendment is a promising agricultural practice that reduces N losses, achieving more efficient use of N fertilizers, and at the same time, contributes to the accumulation of soil organic carbon in soils (Montanarella *et al.* 2013; Field *et al.* 2013). Using Biochar as a soil correction can even return the areas lost for agriculture to production by compensating for acidity, low organic carbon, and low water content (Lehmann *et al.* 2012). Perennial crops are a potentially more sustainable alternative to annual crops, which currently dominate the global food system. Annual crops must be planted every year and, therefore, require routine field operations and precisely calculated costs and management.

MATERIALS AND METHODS

Study area

This research was conducted in two distinct agroecological zones of Southeastern Kazakhstan: the Karasai district of the Almaty region and the Balkhash district in Agrofirma Birlik LLP's fields. These locations were chosen due to their highly degraded soil conditions, which have undergone secondary salinization and nutrient depletion over time. The experimental sites were representative of the challenges faced by agricultural systems in Kazakhstan, where soil degradation, declining organic matter, and reduced water retention capacity impact overall crop productivity. The Karasai district was selected for its proximity to large agricultural production zones, making it an ideal site for assessing biochar's impact on soil restoration in cultivated fields. The Balkhash district, known for its severely degraded irrigated lands, provided an opportunity to evaluate biochar's effectiveness in rehabilitating soils with low organic content and poor structural integrity. The presence of takyroid soils, which are characterized by low humus content and restricted water penetration, posed significant obstacles for crop cultivation, thus making these study sites ideal for analyzing the potential benefits of biochar amendments.

Experimental design

The study consisted of two distinct experiments: vegetation experiments and field trials, both designed to evaluate the impact of biochar on soil properties and plant development under varying application rates. Comprehensive data collection was conducted across both experiments to assess plant development, biomass accumulation, and yield formation under different biochar treatments.

Vegetation experiment

A vegetation experiment is a controlled study designed to investigate the growth, development, and response of plants under specific environmental or treatment conditions. These experiments are commonly used in agricultural research, ecology, and environmental science to assess factors such as soil amendments, irrigation methods, climate effects, and nutrient availability. Vegetation experiments typically involve growing plants in controlled environments, such as pots, greenhouse settings, or designated field plots, where variables like soil composition, water availability, and fertilizer application can be precisely managed. Researchers use these experiments to evaluate how different treatments—such as biochar application, organic fertilizers, or varying irrigation techniques—affect plant germination, biomass accumulation, yield formation, and overall health. The vegetation experiment was conducted using vegetative vessels, with a total of 60 individual vessels, each covering an area of 706.5 cm^2. The soil used in the experiment was extracted from the Balkhash district's degraded lands, ensuring uniformity in soil conditions across all vessels. Biochar was applied at six different doses: 0 (control), 5, 10, 15, 20, and 25 tons ha^{-1}.

Three different irrigated crops were included in the experiment to evaluate the response of various plant species to biochar application:

Rice (Regulus variety).

Spring wheat (Almaken variety).

Soybean (Victory and Zhansaya varieties).

Seed germination, initial root development, and early vegetative growth were carefully monitored under controlled conditions to determine the effectiveness of biochar in improving soil fertility and water retention. Observations of plant development included field germination percentages, growth dynamics, and biomass accumulation at critical phenological stages such as tillering, piping, flowering, and maturity.

Field experiment

A field experiment is a research study conducted in a real-world setting rather than in a controlled laboratory environment. It allows researchers to observe and analyze how different variables interact under natural conditions, making the findings more applicable to practical situations. Field experiments are commonly used in agriculture and environmental science to test hypotheses in realistic scenarios. Unlike laboratory experiments, where conditions are tightly controlled, field experiments introduce treatments or interventions in actual environments, such as farms, forests, or urban areas, to assess their effects. The field experiment was conducted on the Akdalinsky irrigation massif, which is known for its degraded takyroid soils. To assess the impact of biochar application on field crops, six experimental treatments were established:

Control (0 tons ha^{-1} biochar)

5 tons ha^{-1} biochar

10 tons ha^{-1} biochar

15 tons ha^{-1} biochar

20 tons ha^{-1} biochar

25 tons ha^{-1} biochar

Biochar was incorporated into the soil through two distinct tillage approaches:
Autumn application for deep plowing (conducted in October 2022 and October 2024).
Spring application for pre-sowing tillage (conducted in March 2023).
In addition to biochar amendments, the field experiment included a standard fertilization protocol to provide uniform nutrient availability. An amount of 100 kg ha^{-1} of amorphous fertilizer was applied at sowing, followed by 100 kg ha^{-1} of carbamide fertilizer as a top dressing. The consistency in fertilization ensured that variations in plant growth and yield could be attributed to biochar treatments rather than external nutrient supply.

Seed germination and early growth
Seed germination rates were recorded for each biochar treatment to evaluate plant establishment under different soil amendment conditions. The percentage of successfully germinated seeds was determined and compared between control and biochar-treated samples to assess biochar's role in improving seed viability.

Phenological observations
Phenological assessments were conducted at regular intervals to record developmental progress at key growth stages, including:
Tillering phase (early shoot establishment);
Piping phase (stem elongation and early reproductive growth);
Flowering phase (transition to reproductive development);
Maturity phase (grain or pod filling leading to harvest).
Comparisons between biochar-treated plants and control groups were analyzed to determine the extent to which biochar influenced developmental speed and reproductive success.

Biomass accumulation and crop productivity
Biomass accumulation was measured at three distinct intervals across the crop growth cycle:
Tillering stage (initial vegetative development);
Flowering stage (peak biomass accumulation);
Maturity stage (final yield formation).
Measurements were taken in both wet and dry weight forms to assess biochar's influence on plant structural growth and carbon sequestration.

Yield assessment and grain quality
Final grain yields were recorded for all three crops to determine productivity enhancements under biochar treatments. Yield-related parameters included:
Productive tillering (for rice and wheat).
Lake content (grain count per panicle or spike).
Weight of 1,000 grains (a standardized productivity metric).
The collected yield data was analyzed statistically to establish significant correlations between biochar application rates and productivity outcomes.

Statistical analysis
To validate experimental findings, variance analysis (ANOVA) was performed to identify statistically significant differences between biochar treatments. Further, the Least Significant Difference (LSD) test ($p < 0.05$) was applied to compare yield indicators, phenological observations, and biomass accumulation across experimental treatments. Statistical software was utilized to ensure accurate interpretation of results, with confidence intervals calculated for all measured parameters.

RESULTS AND DISCUSSION
Vegetation experience in studying methods and doses of biochar application on degraded soils. To study the methods and doses of biochar application on degraded soils, a vegetation experiment was laid in the fields of the farm "Yrys" of the Karasai district of the Almaty region in fourfold repetition. The number of vessels was 60, the area of one vessel was 706.5 cm^2. Soils for clogging vegetative vessels were selected from a pilot site in Agrofirma Birlik LLP's fields in the Almaty region's Balkhash district. The soils of the experimental site were severely

degraded due to secondary salinization. Variants of the vegetation experiment to study the dose of biochar application at the rate of 0, 5, 10, 15, 20 and 25 tons ha^{-1}. The germination of seeds in the study of the effectiveness of biochar is shown in Table 1.

Table 1. Germination of seeds in the study of the effectiveness of biochar (pcs/s vessel).

Experience options	Rice		Spring wheat		Soybean	
	Sown	Germinating plants	Sown	Germinating plants	Sown	Germinating plants
Without biochar (control)	33	5	31	10	20	4
Biochar (5 tons ha^{-1})	33	25	31	28	20	18
Biochar (10 tons ha^{-1})	33	27	31	29	20	20
Biochar (15 tons ha^{-1})	33	15	31	17	20	13
Biochar (20 tons ha^{-1})	33	30	31	30	20	19
Biochar (25 ton ha^{-1})	33	21	31	28	20	16

Phenological observations of plant development in the vegetation experiment showed that rice seedlings appeared on May 30, wheat on May 25, and soybeans on May 29. Considering the number of plants in one vessel, it was shown that in the variants with the introduction of biochar, the field germination of plants was 10-25% higher than without biochar. At the same time, the higher the dose of the introduced biochar, the higher the value of this indicator. By June 15, the growth and development of rice and wheat in the non-biochar variants slowed down, and the earing and panicle ejection phase stopped altogether (Table 2 and Fig. 1). The maturation phase for these crops is fixed on variants with the introduction of 10-15 tons ha^{-1} of biochar on medium-saline soils. As for soybean plants, in many variants, their growth and development continued until maturation. The structure of rice, wheat, and soybean harvest has been determined. In the vegetation experiment, at different doses of biochar application, the highest indicators were found in variants 15, 20, and 25 tons ha^{-1}. At a dose of biochar per 10 tons ha^{-1}, the yield of rice was 28.0 g vessel^{-1}, spring wheat 30.3 g vessel^{-1}, and soybeans 53.8 g vessel^{-1}. At a dose of biochar per 15 tons ha^{-1}, the yield of rice was 46.5 g vessel^{-1}, spring wheat 65 g vessel^{-1}, and soybeans 80.0 g vessel^{-1} (Table 3).

Table 2. Phenology of rice and soybean development depending on the application of biochar.

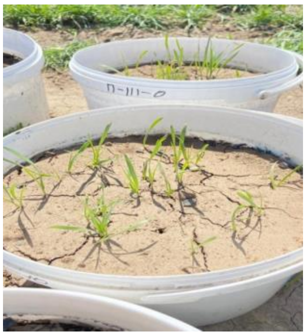
Doses of biochar application (tons ha^{-1})	Rice						
	Shoots	Tillering	Piping	Sweeping out	Milk ripeness	Waxy ripeness	Full ripeness
Without biochar (control)	26-29.04	28-30.05	-	-	-	-	-
5	24-27.04	4-8.05	15-17.06	26-28.07	4-7.08	11-13.08	20-23.09
10	24-26.04	4-8.05	13-16.06	25-26.07	4-6.08	10-12.08	19-22.09
15	23-24.04	2-4.05	10-12.06	24-26.07	3-5.08	9-11.08	17-22.09
20	23-26.04	2-5.05	11-13.06	24-26.07	3-5.08	9-11.08	17-22.09
25	23-26.04	3-5.05	11-13.06	24-26.07	3-5.08	9-11.08	17-22.09
Doses of biochar application (tons ha^{-1})	Soybean						
	Shoots	1-3 leaves	Branching	Budding	Blossom	Bean formation of soybeans	Maturation
Without biochar (control)	28-30.04	-	-	-	-	-	-
5	28-30.04	4-8.05	-	-	-	-	-
10	28-30.04	01-3.05	15-28.06	10-15.07	26-28.07	06-08.08	15-20.09
15	25-26.04	30-01.05	19-22.06	05-8.07	15-17.07	29-31.07	05-8.09
20	27-28.04	01-3.05	22-26.06	8-12.07	20-23.07	04-07.08	10-15.09
25	27-28.04	01-3.05	22-26.06	8-12.07	20-23.07	04-07.08	10-15.09

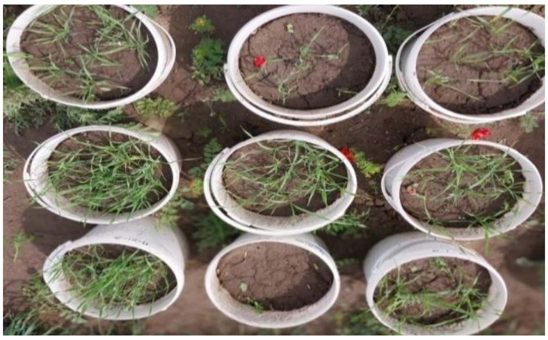
Table 3. Crop yield in the study of the effectiveness of biochar (g $vessel^{-1}$).

Experience Options	Rice	Spring wheat	Soybean
Without biochar (control)	-	-	10,6
Biochar (5 tons ha^{-1})	30.5	57.3	78.6
Biochar (10 tons ha^{-1})	28.0	30.3	53.8
Biochar (15 tons ha^{-1})	46.5	65.5	80.0
Biochar (20 tons ha^{-1})	46.0	66.2	84.2
Biochar (25 tons ha^{-1})	47.5	60.8	83.9

Field experience in studying the effectiveness of biochar on degraded soils

Field experiments on the Akdalinsky irrigation massif's degraded soils were laid in Agrofirma Birlik LLP's fields in the Almaty region's Balkhash district. The following crops were sown on degraded soils: rice – Regulus variety, soy – Victory and Zhansaya, and optional wheat - Almaken variety. 100 kg ha^{-1} of amorphous were introduced simultaneously with sowing. Rice crops were then top-dressed with 100 kg ha^{-1} of carbamide fertilizer. According to the scheme of field experience, biochar was introduced in autumn for dump plowing (October 21, 2022, and October 20, 2024), and in spring for pre-sowing tillage (March 20, 2023). Field experience options for studying the effectiveness of biochar: without biochar (control); biochar 5, 10; 15, 20, and 25 tons ha^{-1}. Records and observations were carried out on the growth and development of plants on takyroid soils of the Akdalinsky irrigation massif in the fields of Agrofirma Birlik LLP. Methods and doses of biochar application on degraded irrigation soils significantly impact the field germination rate of the studied crops. The germination rate of rice seeds ranged from 21 to 76%. The seeds sown in the variant with flooding and without biochar application differed in the lowest field germination and the highest in the variant of drip irrigation with biochar application of 15 and 20 tons ha^{-1} (Figs. 2-4). Soybean plants were distinguished by the friendly emergence of seedlings, advances in growth and development, more intensive plant biomass accumulation, and, ultimately, the formation of a high yield. Phenological observations of plant development in the vegetation experiment showed that rice seedlings appeared on May 28, wheat on May 24, and soybeans on May 30. Considering the number of plants per square meter, it was shown that in the variants with the introduction of biochar, the field germination of plants was 15-25% higher than without it. At the same time, the higher the dose of the introduced biochar, the higher the value of this indicator. The maturation phase for these crops is fixed on variants with the introduction of 15-20 tons ha^{-1} of biochar on medium-saline soils.





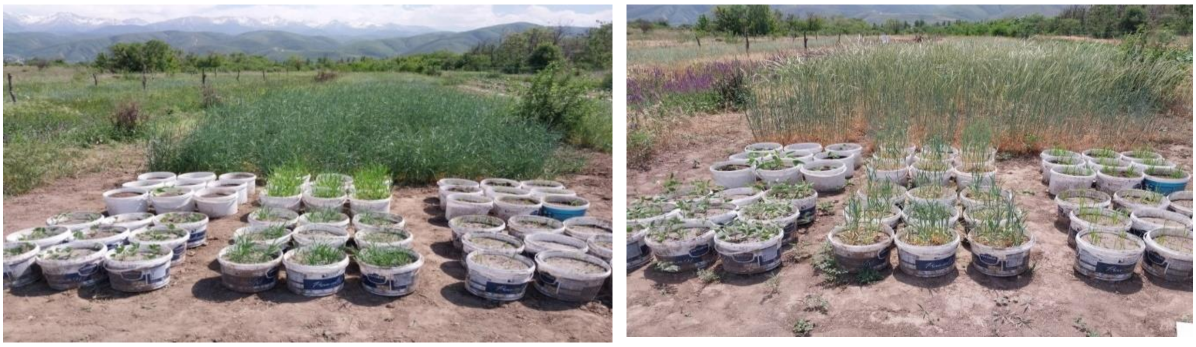
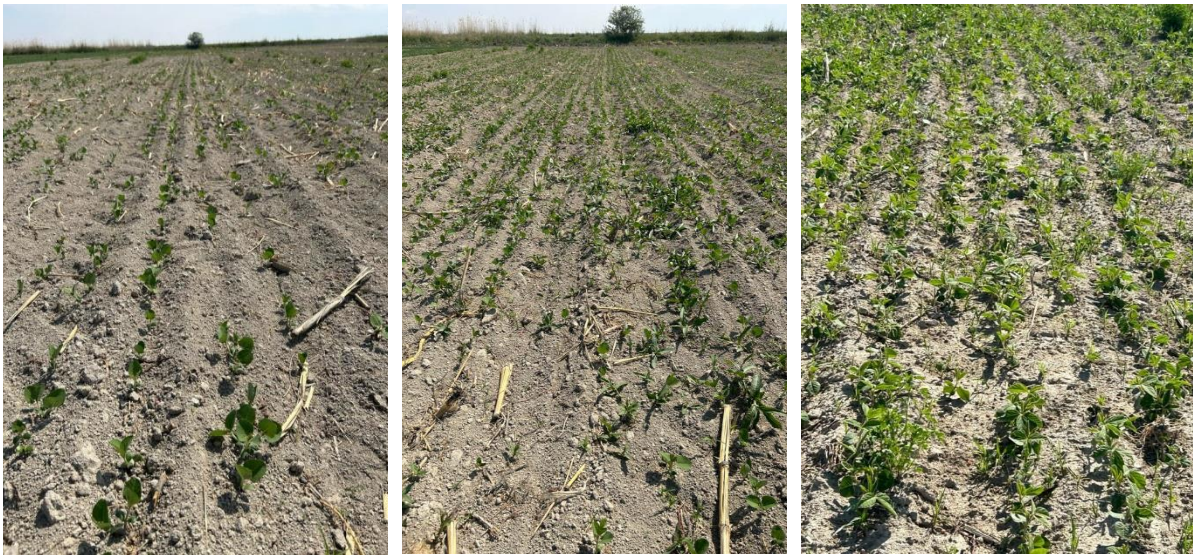
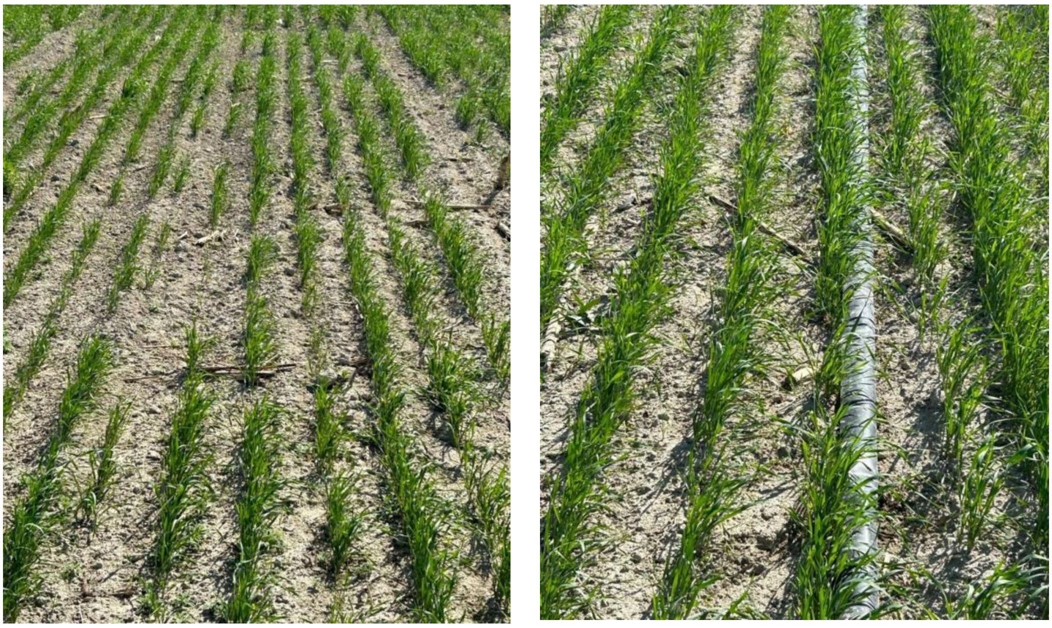


Fig. 1. Vegetation experience, application of biochar to saline soil of the Akdalinsky irrigation massif.



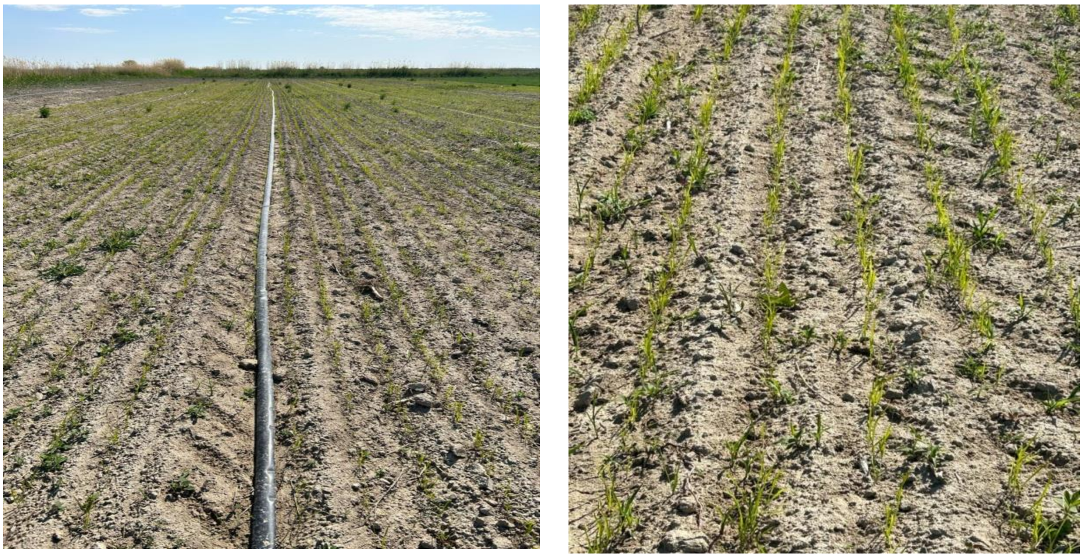
5 tons ha^{-1} 10 tons ha^{-1} 15 tons ha^{-1}

Fig. 2. Soybean sowing with the introduction of various doses of biochar.



15 tons ha^{-1} 20 tons ha^{-1}

Fig. 3. Sowing of optional Almaken wheat with the introduction of various doses of biochar.



10 tons ha^{-1} 20 tons ha^{-1}

Fig. 4. Sowing rice with the introduction of various doses of biochar.

In 2022, rice formed an average of 150-250 g of raw plant biomass per square meter in the variants when applying biochar at 10 and 15 tons ha^{-1} during the tillering phase. In the piping phase, the crude mass averaged 600-700 g m^{-2}. The crude mass of soybean plants at the beginning of the growing season and during the early ripening phase were 300 g m^{-2} and 1420 g m^{-2} respectively. The dynamics of accumulation of the raw mass of spring wheat plants during the tillering phase, and dry weight amounted to 150-200 and 70-80 g m^{-2} respectively. In addition, during the flowering phase, the crude biomass and the dry mass were 2933-3000 and 956-1050 g m^{-2} respectively. In 2023, the crude mass of soybean plants during the branching phase and at the beginning of maturation were 228 and 1620 g m^{-2}. The crude mass of facultative wheat plants accumulated during the tillering phase was 200 g m^{-2}, while the dry mass was 120 g m^{-2}. In the tubing phase, the crude mass was 325 g m^{-2}. Moreover, during the flowering phase, the crude biomass was 3000-4000 g m^{-2}. In the variants, when biochar was applied at 10 and 15 tons ha^{-1} during the tillering phase, rice formed an average of 150-250 g of raw plant biomass per square meter. During the piping phase, the crude mass averaged 600-700 g m^{-2}.

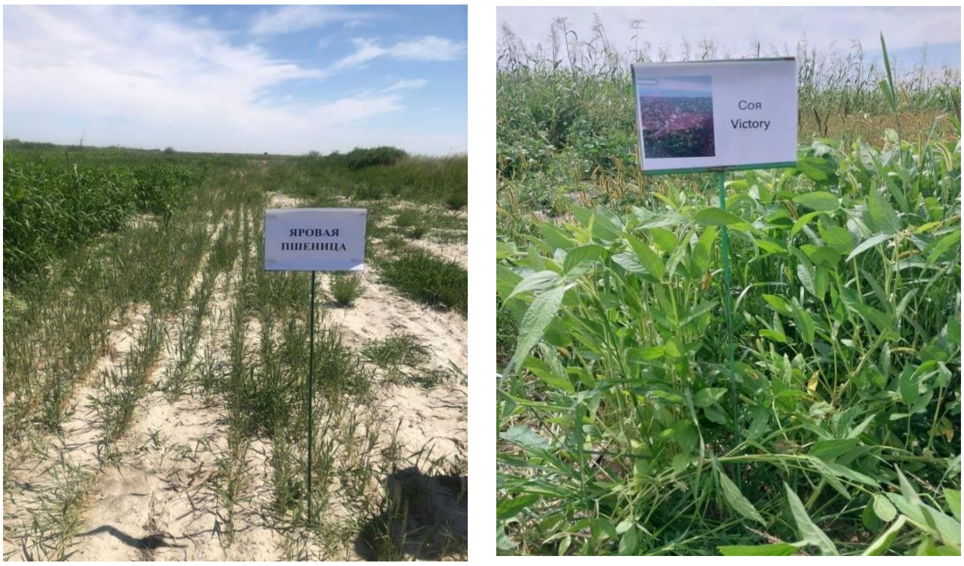


Fig. 5. The state of spring wheat and soybean crops, 2022.

The introduction of biochar on degraded soils significantly affects the elements of the yield structure of the studied crops. On rice plants, biochar and drip irrigation positively affect the formation of the panicle's lake content and the grain's absolute weight. The improvement of the agrophysical and agrochemical properties of degraded irrigated takyroid soils of the rice-growing zone of south-east Kazakhstan when applying biochar for basic tillage is ultimately reflected in the formation of the grain yield of the studied crops (Table 4). As can be seen from the data in Table 8, the use of biochar, depending on the application doses, increases the yield of soybeans by 0.16-1.48 tons ha^{-1} or 10-96%, shala rice by 0.17-0.97 tons ha^{-1} or 6-36%, and spring wheat by 0.05-1.8 tons ha^{-1} or 2-65%. Generally, over 3 years, biochar ensures the production of 1.34-3.68 tons of additional rice, wheat, and soybeans grains.

Table 4. Crop yield under drip irrigation, depending on the methods and doses of biochar application.

Experience options	Yield (tons ha^{-1})			The amount of crop yield for 3 years (tons ha^{-1})	± the increase
	Soybean	Rice	Spring wheat		
Without biochar (control)	1.54	2.73	2.76	7.03	-
Biochar (5 tons ha^{-1})	1.77	2.45	2.81	7.03	-
Biochar (10 tons ha^{-1})	2.03	2.90	3.44	8.37	+1.34
Biochar (15 tons ha^{-1})	3.06	3.64	3.87	10.57	+3.54
Biochar (20 tons ha^{-1})	3.02	3.63	4.06	10.71	+3.68
The smallest significant difference 0.05; tons ha^{-1}	0.21	0.36	0.52		

At the same time, an elevation in rice yield is achieved by increasing the productivity of tillering and the weight of 1000 grains, and spring wheat by upraising the productive business and laceration of the ear (Table 5).

Table 5. Structure of the grain crop yield depending on the methods and doses of biochar application.

Doses of biochar application (tons ha^{-1})	Number of plants (pcs m^{-2})		Productive bushiness		Lake content (pcs)		Weight of 1000 grains, g	
	Rice	Spring wheat	Rice	Spring wheat	Rice	Spring wheat	Rice	Spring wheat
0	152±8	186±13	1.64±0.10	1.42±0.09	45±3	35±3	32.1±1.6	34.5±1.0
5	165±11	204±15	1.78±0.10	1.50±0.10	46±3	35±3	30.9±1.0	33.3±1.0
10	143±9	177±12	1.88±0.09	1.63±0.11	49±3	39±4	34.2±1.5	34.0±1.3
15	160±10	196±12	2.01±1.11	1.77±0.11	43±2	39±3	37.8±1.7	34.9±1.3
20	158±7	188±12	1.82±0.09	1.64±0.08	41±2	40±5	40.0±1.9	34.5±1.5

The variant without biochar had a low mass index of 1000 grains of rice—32.1 g, while the variants with biochar had the highest mass of 1000 grains—15 and 20 tons ha^{-1}. Introducing biochar at doses of 15-20 tons ha^{-1} for basic tillage improves the bulk mass, increasing the content of agronomically valuable and water-resistant aggregates of the arable soil layer. There is a significant increase in the content of labile humus and mobile phosphorus. The improvement of the agrophysical and agrochemical properties of degraded takyroid soils ultimately leads to an increase in the productivity of rice crop rotation due to the action and after effect of biochar applied for dump plowing. The yield of rice and spring wheat increases mainly due to the productivity of tillering, soybeans, and additional legume formation.

CONCLUSION

The use of biochar, depending on the application doses, increases the yield of soybeans by 0.16-1.48 tons ha^{-1} or 10-96%, rice by 0.17-0.97 tons ha^{-1} or 6-36%, and spring wheat by 0.05-1.8 tons ha^{-1} or 2-65%. In general, over 3 years, biochar ensures the production of 1.34-3.68 tons of additional grains of rice, wheat, and soybeans in total. Introducing biochar in doses of 15-20 tons ha^{-1} for basic tillage improves the bulk mass, increasing the content of agronomically valuable and water-resistant aggregates of the arable soil layer.

ACKNOWLEDGEMENT

The research was carried out as part of the project titled "Agrobiological Methods for Restoring Fertility in Degraded Irrigated Lands of Southeast Kazakhstan," with the project reference number IRN AP13068063.

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Bibliographic information of this paper for citing:

Doszhanova, A, Mussina, M, Nurgaliyeva, G, Mukhametkarimov, K, Nurgaliyev, A, Sembayeva, A 2025, Cultivation of irrigated crops in the application of biochar technology in the Southeast Kazakhstan, Caspian Journal of Environmental Sciences, 23: 425-435.