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Effect of drip irrigation on changes in the agrochemical and agrophysical properties of light-ash soils in the foothill zone of Ili Alatau, Kazakhstan

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ABSTRACT

The article presents the results of research to assess the effect of drip irrigation on the agrochemical and agrophysical properties of light chestnut soils, as well as on the formation of yields of major crops in the foothill zone in Ili Alatau, Kazakhstan. The objects of research were winter wheat, soybeans and corn cultivated in irrigated crop rotation. In the course of field experiments, we studied changes in the density of soil composition, the content of agronomically valuable and durable aggregates, as well as the dynamics of easily hydrolyzable nitrogen, mobile phosphorus and exchangeable potassium during the growing season. It has been established that the use of drip irrigation improves the structural condition of light chestnut soil, increases the proportion of agronomically valuable aggregates and optimizes agrophysical parameters without exceeding the permissible values of the density of addition. It is shown that the maximum values of nutrients in the soil are observed in the middle of the growing season, and by the time of harvest, their content decreases due to active absorption by plants. With optimal agrochemical parameters, high yields are achieved: winter wheat: up to 5.5 tons ha^{-1}, soybeans: up to 4.7 tons ha^{-1} and corn: up to 17.2 tons ha^{-1}.

Keywords: Soil fertility, Winter wheat, Soybeans, Corn, Drip irrigation, Cultivation technology, Fertilizer, Yield
Article type: Research Article.

INTRODUCTION

Currently, due to the development of irrigation, there is no doubt that drip irrigation is one of the most promising irrigation methods. This irrigation method allows us to create the most favorable conditions for plants, provide water supply directly to the roots of plants, and automate the irrigation process. Increasing the efficiency of this irrigation method is based on obtaining maximum production at a minimum cost of irrigation water and labor. In addition, global warming is gradually undermining food security worldwide, especially in developing countries (Behnassi *et al.* 2021). Given its rapidly growing nature, the world's population is expected to reach 9.8 billion by 2050, as well as a projected significant increase in food demand (Valin *et al.* 2014). In this regard, feeding the growing global population is the most important task that humanity has to solve (Foley *et al.* 2011). The search for optimal ways to provide the population with food consists in vertically increasing grain yields, which is possible through improved water-saving technology, including the use of effective mineral fertilizers. Currently, Kazakhstan faces a water deficit of over 20%, and as consumption continues to rise while water resources dwindle,

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this deficit is projected to increase further. In this regard, the prospects for water supply in the southern and southeastern regions of Kazakhstan, which are *highly* dependent on transboundary waters, as well as the deterioration of hydro-reclamation systems and the unstable structure of agricultural production, as well as global climate change have a more negative impact on the territory of Kazakhstan compared to the global average trend (Ibatullin *et al.* 2015). This situation poses a serious threat to the country's water supply and exacerbates desertification processes in the affected areas. Moreover, the results from annual monitoring of irrigated lands, conducted by hydrogeological and reclamation expeditions, indicate that over 50% of these lands experience varying degrees of salinity, while more than 30% are classified as brackish. Additionally, the significant volumes of drainage and wastewater produced on irrigated lands (ranging from 30% to 50% of the water supply) and in populated areas (from 10% to 30%) contaminate water sources and degrade the ecological and reclamation conditions of both irrigated lands and surrounding territories (Kvan *et al.* 2011). Numerous studies, mainly conducted abroad, show that drip irrigation of agricultural crops is the most effective way of rational use of irrigation water. As a result, the drip irrigation system is more efficient than other irrigation methods (Cassel Sharmasarkar *et al.* 2001; Topak *et al.* 2011; Kiymaz & Ertek 2015). In recent years, we have conducted research on the effectiveness of drip irrigation of the main field crops in the irrigated lands of the south and southeast of Kazakhstan - rice, sugar beet, corn and soybeans (Zhapayev *et al.* 2023; Ospanbayev 2025a, Sembayeva *et al.* 2025a). The research results have shown a fairly high efficiency of drip irrigation in the cultivation of the most water-intensive field crops, such as rice and sugar beet. Our previous research has proved the economic, especially environmental, effectiveness of drip irrigation in the South-east Kazakhstan. The optimal irrigation regime, timing, methods and doses of mineral fertilizers have been established (Kenenbayev *et al.* 2016; Ospanbayev 2025b; Sembayeva *et al.* 2025b).

MATERIALS AND METHODS

To solve the tasks set, multifactorial field experiments were conducted at the pilot demonstration site of the Kazakh Scientific Research Institute of Agriculture and Crop Production LLP located in the foothill irrigated zone of the Trans-Ili Alatau on light chestnut soils. The objects of research were the main crops of the irrigated zone of the south and south-east Kazakhstan: winter wheat, soybeans and corn. The soils of the experimental site are light chestnut foothill soils with high carbonate content. According to the mechanical composition of soils, it belongs to coarse-dusty medium loams, the content of physical clay is 39-42%, coarse dust is 45-51%, silt is 12-17%. In the upper horizon it contains humus up to 2.02%, 0.12-0.14% of gross nitrogen. Basic tillage was carried out to a depth of 25-27 cm with harrowing and pre-sowing cultivation, during sowing nitroammophos was introduced in a physical weight of 300 kg ha^{-1}. This rate of application of mineral fertilizers is recommended for the conditions of the south-east Kazakhstan. After plowing, small-scale planning is carried out - an obligatory element on regularly irrigated lands, followed by pre-sowing tillage. According to the scheme of field experience, dump plowing was carried out with a Grandtor rotary plow to a depth of 25-27 cm, sowing was carried out with an Agromaster pneumatic precision seeder. Laboratory studies and analyses of soils and plants were conducted in an accredited analytical laboratory of the Kazakh Scientific Research Institute of Agriculture and Crop Production LLP. The drip irrigation system included: a water intake system connected to irrigation hydrants, a purification and fertigation system, main pipes, distribution pipes, and irrigation belts for surface drip irrigation. The field experience was laid, observations and records were carried out according to the methodology of B. A. Dospekhov (Dospekhov 1985). The determination of the water-physical properties of the soil was carried out according to the method of N.A. Kachinsky (Kachinsky 1970). Determining nitrates continued by the TsINAO method, GOST26488-85. Mobile phosphorus and potassium identification in carbonate soils sought the approach of the Machigin method with modification of TsINAO.GOST26205-91 and processing of yield data using Dospekhov's method (Dospekhov 1985).

Meteorological conditions

According to long-term data from the meteorological station of the Kazakh Scientific Research Institute of Agriculture and Crop Production, the average annual air temperature was +7.6 °C. The hottest month of the year was July with an average monthly air temperature of 24.1 °C. Stable snow cover is formed in late November - early December and lies for 85-100 days. The sum of positive temperatures during the active growing season of plants (April-September) reaches 3429 °C. The amount of precipitation in the region over the same period ranges from 110.2 to 435.3 mm. According to the long-term average data, the greatest amount of precipitation falls in spring. The meteorological conditions in 2019 differed significantly from the average annual values, as April turned out to be wetter (183 mm) and warmer compared to long-term indicators, especially in the third decade (Table 1). The temperature indicators in May were on average below the level of long-term indicators, precipitation was 2 times less than the annual average, plus they all fell in the first decade of May, and the second and third were characterized by a lack of moisture. All summer months (June-August), the temperature background was 1.1-2.8 degrees hotter than the annual average. Although precipitation was at or above the long-term level, it also fell 1-2 times in May at the beginning of the month. High temperatures both during the day and at night led to the appearance of an air drought. The first decade of September was characterized by heavy rainfall, the temperature background was 2.5 degrees above the annual average, and 67.2 mm of precipitation fell. A total of 455.6 mm fell during the growing season, compared to 237.7 mm of average annual rainfall. The meteorological conditions in 2020 have created favorable conditions for the growth and development of corn plants. As in 2019, there was a heavy rainfall of 146.7 mm in April. It should be noted that for all five months during the growing season of corn, the amount of precipitation exceeded the annual average by 5.3-90.2 mm, with the exception of June, where it was observed below the annual average by 11.3 mm. According to the data, the spring of 2021 turned out to be wetter (88.9 mm) and warmer than the annual average, especially in March, characterized by an excess of 3.4 °C. Precipitation in March contributed to the accumulation of sufficient moisture in the soil to produce friendly corn seedlings. Based on the temperature background, all summer months, except August, were 1.9 °C–2.7 °C hotter than the annual average, and in terms of precipitation, they were 30.8 mm lower than normal. Agrometeorological conditions showed that the summer was extremely dry and hot. All these environmental factors have influenced the growth and development of agricultural crops and, ultimately, their yields.

Table 1. Average monthly air temperature and precipitation during the growing season.

Month	Air temperature (°C)				Precipitation (mm)			
	2019	2020	2021	Long-term mean	2019	2020	2021	Long-term mean
April	12.4	14.2	12.4	10.4	183.0	146.7	56.3	56.5
March	16.9	18.7	19.4	16.4	39.3	73.5	81.6	61.6
June	22.3	16.5	23.1	21.2	72.7	42.6	20.9	53.9
July	26.9	24.4	26.9	24.1	25.7	38.1	22.8	26.6
August	24.9	24.1	24.0	22.1	67.7	43.7	27.2	21.2
September	18.6	16.8	20.5	16.0	67.2	21.2	1.6	15.9
In 6 months	20.3	19.1	21.1	18.4	455.6	365.8	210.4	235.7

RESULTS AND DISCUSSION

Agrochemical parameters of soil

Under winter wheat crops during its growing season, the ranges of fluctuations in nutrients were: easily hydrolyzable nitrogen: 51-63 mg kg^{-1}, mobile phosphorus: 32-42 mg kg^{-1}, and exchangeable potassium: 309-394 mg kg^{-1}. By these optimal indicators of nutrition elements, the yield of winter wheat was 5 tons ha^{-1}. Table 2 shows the change in the content of nutrients in the soil during the growing season of crops. The determination of the content of easily hydrolyzable nitrogen in the soil under corn sowing showed that its amount increased from 52 mg kg^{-1} in early spring to 68 mg kg^{-1} by the middle of the growing season and decreased to 59 mg kg^{-1} by harvest. When harvesting corn for grain, the yield was 12.6-17.0 tons ha^{-1}. Therefore, when the content of easily hydrolyzable nitrogen during the growing season was 52-68 mg kg^{-1}, mobile phosphorus was 47-57 mg kg^{-1}, and exchangeable potassium was 318-386 mg kg^{-1}, they were considered optimal, since with such indicators of nutrients, the indicated yield was obtained.

Table 2. Changes in the content of nutrients in the soil during the growing season of crops.

Culture	Easily hydrolyzable nitrogen (mg kg^{-1})			Mobile phosphorus (mg kg^{-1})			Exchangeable potassium (mg kg^{-1})		
	During sowing	Midgrowing season	Before harvesting	During sowing	Midgrowing season	Before harvesting	During sowing	Midgrowing season	Before harvesting
Winter wheat	51	63	53	37	42	32	328	394	309
Soy	43	47	42	33	43	37	313	375	322
Corn	52	68	59	47	57	52	318	386	334

Under soybean crops, the amount of easily hydrolyzable nitrogen in the soil varied during the growing season in the range of 42-47 mg kg^{-1}, mobile phosphorus 33-43 mg kg^{-1}, and exchangeable potassium 313-375 mg kg^{-1}. By these optimal agrochemical parameters, soybean yields of 4.6 tons ha^{-1} were achieved.

Agrophysical properties of soil

One of the main indicators when studying the methods of basic tillage is the density of the soil. In the structural soil, optimal conditions are created for the water, air and thermal regimes of soils, on which the development of microbiological activity, the mobilization of nutrients and their availability to plants depend. At the same time, agronomically valuable and durable aggregates largely determine the agricultural production characteristics, as well as the level of soil fertility. As noted by Zhapayev *et al.* (2023a), the content of agronomically valuable aggregates (10-0.25 mm) was more influenced by tillage methods and provided a good and excellent structural condition of 0-40 cm layer during the growing season of crops 65-69% with dry sieving. The results of the study showed that the agrophysical properties of light chestnut soil varied depending on the crop and the growing season. In all variants of the experiment, there was a slight increase in the density of soil composition by the time of harvest, which is associated with the compacting effect of precipitation and technological operations. The lowest addition density in spring was recorded under winter wheat (1.17 g cm^{-3}), while under corn this indicator was the maximum (1.22 g cm^{-3}). However, the values did not exceed the optimal limits for cultivated crops.

Table 3. Changes in the agrophysical properties of light chestnut soil.

Culture	Density (g cm^{-3})		Agronomically valuable aggregates (%)		Water-resistant units (%)	
	During sowing	Before harvesting	During sowing	Before harvesting	During sowing	Before harvesting
Winter wheat	1.17	1.20	58	62	12.7	16.2
Soybean	1.20	1.21	68	71	10.8	11.9
Corn	1.22	1.23	61	67	11.9	14.6

By the end of the growing season, the content of agronomically valuable aggregates increased in all crops, especially soybeans and corn by 3-6%, which indicates an improvement in the structural condition of the soil. A similar trend was observed for water-resistant aggregates, the proportion of which increased during the growing season, most notably for winter wheat and corn.

Table 4. Winter wheat yield (c ha^{-1}).

Varieties	Irrigation methods	
	Moisture-charging	Call sign
Steklovidnaya-24	55.6	42.1
Egemen -20	47.9	39.1
Vavilov -12	44.4	33.0
Zhetisu	40.5	34.9
China 41	41.3	35.3
China 53	38.0	32.0

The formation of winter wheat crop in the crop rotation. The research results showed that by traditional tillage, water-charging irrigation provided higher yields of winter wheat compared to reverse irrigation for all the studied varieties. The advantage of water–charging irrigation was 6.6-13.5 c ha^{-1}, which indicates its high efficiency in experimental conditions. The highest yield was obtained from the Vitreous variety -24: 55.6 c ha^{-1} with moisture-charging irrigation, which confirms its high adaptive and productive potential. The minimum yield values were recorded for the China 53 variety, especially with excessive watering (32.0 c ha^{-1}).

Features of the formation of soybean crop varieties in crop rotation. The peculiarities of soybean crop formation in crop rotation are determined by a combination of varietal specificity and agrotechnical factors. The most rational way is to include soybeans in crop rotations after grain crops with minimal contamination, the use of optimal tillage and ensuring an adequate level of nutrition and moisture supply. The research results show that the dynamics of biomass accumulation in soybean varieties Zhansaya and Aisaule significantly depended on both the irrigation method and the sowing scheme. By comparing irrigation methods, it can be noted that drip irrigation provided higher plant mass values compared to subsurface drip irrigation, which is probably due to a more uniform distribution of moisture in the upper root layer and better conditions for photosynthetic activity of plants. The greatest accumulation of soybean biomass was observed with drip irrigation and an ordinary method of sowing, especially in the Zhansaya variety, which indicates the high efficiency of this combination of agrotechnical techniques.

Table 5. Yield of soybean varieties depending on irrigation and sowing methods (kg ha^{-1}).

Irrigation methods	Variety	Methods of sowing	Yield (c ha^{-1})
Drip irrigation	Zhansaya	Ordinary sowing 15 cm	46.8
		Wide-row 45 cm	36.5
		Double-row 30 × 70 cm	33.4
	Aisaule	Ordinary sowing 15 cm	46.7
		Wide-row 45 cm	35.5
		Double-row 30 × 70 cm	35.1
Subsurface drip irrigation	Zhansaya	Ordinary sowing 15 cm	43.6
		Wide-row 45 cm	34.5
		Double-row 30 × 70 cm	33.0
	Aisaule	Ordinary sowing 15 cm	43.3
		Wide-row 45 cm	33.7
		Double-row 30 × 70 cm	34.0

Table 5 shows that the yield of soybeans largely depends on the irrigation method and the sowing scheme. The highest rates were obtained by drip irrigation and ordinary sowing (15 cm). Under these conditions, the Zhansai variety provided a yield of 46.8 c ha^{-1}, and the Aisaule variety 46.7 c ha^{-1}. As row spacing increased, yields decreased. Thus, with wide—row sowing (45 cm), the decrease averaged 10-11 kg ha^{-1}, and with double-row (30 × 70 cm): up to 13-14 kg ha^{-1} compared to ordinary sowing. By subsurface drip irrigation, the yield was generally lower by 2-3 c ha^{-1} compared to surface drip irrigation, however, a similar pattern remained: — the maximum yield by ordinary sowing, while the minimum by double-row. Thus, the highest yield of soybeans was obtained with drip irrigation and ordinary sowing (15 cm), where the Zhansaya and Aisaule varieties produced a yield of 45-47 kg ha^{-1}. The optimal combination of conditions for soybean cultivation in the study area was drip irrigation with ordinary sowing.

Study of the features of corn crop formation in crop rotation. An analysis of the data in Table 6 shows that the timing of the phenological phases of corn development under drip irrigation conditions was relatively aligned in all the hybrids studied. Seedlings were formed simultaneously on May 22, which indicates favorable conditions for germination and uniformity of crops. The highest yield was obtained from the hybrid DKC 6777: 172.4 kg ha^{-1}, which is explained by the extended growing season and more complete use of moisture and nutrients. High rates were also noted in the hybrids DKC 5810 (161.0 c ha^{-1}) and the domestic hybrid Tauelsizdik 20 (160.5 c ha^{-1}), which were almost as productive as their foreign counterparts.

Table 6. Crop formation of corn hybrids of domestic and foreign breeding in irrigated crop rotation with drip irrigation (c ha^{-1}).

Naming of hybrids	Phases of plant development				Yield (c ha^{-1})
	shoots	11-13 leaves	throwing out the panicle	full ripeness	
DKC 6777	22.05	01.07	26.07	11.09	172,4
DKC 5911	22.05	25.06	22.07	05.09	130,6
DKC 5810	22.05	25.06	19.07	05.09	161,0
DKC 5709	22.05	25.06	22.07	05.09	154,4
Tauelsizdik 20	22.05	28.06	22.07	05.09	160,5
Turan 480	22.05	25.06	19.07	01.09	136,7
Dala Aruy	22.05	25.06	19.07	28.08	127,6

In conditions of drip irrigation, the hybrid DKC 6777 proved to be the most productive, producing a maximum yield of 172.4 c ha^{-1}. Among domestic hybrids, Tauelsizdik 20 showed a high level of productivity, which indicates its good adaptability and prospects for cultivation in irrigated crop rotation. In general, an increase in the length of the growing season exhibited a positive effect on the formation of the corn crop. The introduction of drip irrigation technology in the cultivation of soybeans and corn has shown high economic efficiency. Despite the higher total costs of growing soybeans (546.9 thousand tenge ha^{-1}) compared to corn (225.2 thousand tenge ha^{-1}), soybeans provided a large net profit (1203.1 thousand tenge ha^{-1}) due to the high cost of products.

Table 7. Effectiveness of the introduction of soybean and corn cultivation technology for drip irrigation.

Indicators	Culture	
	soybean	corn
Yield (tons ha^{-1})	4.6	13.0
Cost of production, thousand tenge	1750.0	1000.0
Total costs, thousand tenge	546.9	225.2
including:		
drip irrigation	402.2	240
fertilizer	68.3	30.5
plant protection products	76.4	32.4
agricultural work	42.0	46.3
Net profit, thousand tenge	1203.1	774.9
Profitability (%)	220	345

Corn generated a higher level of profitability at a lower cost (345%), due to the optimal cost-revenue ratio. A significant share of the costs in the cost structure of both crops was the cost of drip irrigation: 73.6% for soybeans and more than 100% relative to individual items for corn, which underlines the key role of this technology in crop formation.

CONCLUSION

The conducted studies have shown that the use of irrigation and rational agricultural technologies has a significant impact on the agrophysical and agrochemical properties of light chestnut soil, as well as on the formation of crop yields. It was found that during the growing season, a slight increase in soil density was observed under winter wheat, soybeans and corn, while its values did not exceed the optimal limits. At the same time, an increase in the content of agronomically valuable and water-resistant aggregates was noted by the time of harvest, which indicates an improvement in the structural condition of the soil and favorable conditions for plant growth and development. An analysis of the dynamics of nutrients showed that the maximum content of easily hydrolyzable nitrogen, mobile phosphorus and exchangeable potassium were observed in the middle of the growing season, after which they decreased before harvesting due to intensive consumption of nutrients by agricultural crops. The most pronounced changes in the supply of nutrients to the soil were recorded under corn. Yield studies have shown that with traditional tillage, water-charging irrigation provided a higher level of productivity of winter wheat compared to reverse irrigation for all the studied varieties. The highest yield was obtained from the Vitreous-24 variety. By drip irrigation, soybeans and corn produced high and stable yields, which confirms the effectiveness of this technology in conditions of irrigated agriculture. The economic assessment showed that the introduction of soybean and corn cultivation technology with drip irrigation is highly effective. High net profit and profitability levels have been achieved, especially in corn cultivation, which makes these technologies economically feasible for production. Thus, the use of drip irrigation in combination with rational agrotechnical techniques contributes to improving soil condition, increasing yields and economic efficiency of crop cultivation in light chestnut soils.

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