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CORN HYBRIDS ASSESSMENT FOR GRAIN YIELD UNDER THE SOIL TILLAGE REGIMES AND DRIP IRRIGATION IN SOUTHEAST KAZAKHSTAN

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SUMMARY

For the rational use of water resources, the use of drip irrigation system for corn (*Zea mays* L.) crop in Southeast Kazakhstan is a chief recommendation. The relevant research aimed to study the influence of soil tillage methods and drip irrigation systems on corn grain yield, carried out in 2019–2021 at the Kazakh Research Institute of Agriculture and Plant Growing, Almalybak, Kazakhstan. During the research, the soil tillage provided a greater supply of plant residues in the cultivated layer due to better soil crumbling. With traditional and no-tillage, a slight decrease contributed to soil density, and agronomically valuable aggregates amounted to 62%–73%, indicating an excellent aggregate state of the soil. The application of ammonium nitrate and water-soluble mineral fertilizer through fertigation helps maximize the content of hydrolyzed nitrogen (61–68 mg/kg), mobile phosphorus (49–57 mg/kg), and exchangeable potassium (386–394 mg/kg). It proved aside with moldboard plowing, it is also effective with zero tillage. With drip irrigation, the additional use of mineral fertilizers promotes to increase the corn grain yield from 0.87 to 2.85 t/ha. However, the formation of corn grain yield largely depended on the use of mineral fertilizers, and the share of the contribution was mainly reliant on the year of research, ranging from 52.2% to 56.9%.

Keywords: Corn (*Z. mays* L.), hybrids, soil tillage, drip irrigation, fertilizers, soil fertility, yield traits, productivity

Key findings: For the rational use of water resources, using the drip irrigation system in corn (*Z. mays* L.) crop is a chief recommendation. The use of mineral and complex water-soluble fertilizers helps to improve corn productivity.

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INTRODUCTION

Corn (*Zea mays* L.) is a currently grown crop in 170 countries and produces more than 35% of the world's food supply. It occupies a cultivated area of about 200 million hectares, with about 380 million tons of corn grains harvested every year (FAO, 2022). Corn has become one of the economically important crops worldwide. Therefore, its stable productivity is equally crucial for industrialized and developing countries. In the ranking, the USA leads, followed by China, Brazil, the European Union, and Argentina (Petit, 2017). According to the Ministry of Agriculture of the Republic of Kazakhstan, the area under corn rose by 12,800 hectares and brought to 193,800 hectares in 2023 (180,900 hectares in 2022). The 1.207 million tons of corn grains threshed had an average yield of 6.58 t/ha, while in 2022, the average yield was 5.7 t/ha.

Ensuring food security of Kazakhstan, the required increase in the production of corn grains will stimulate the agriculture sector of the South and Southeast of Kazakhstan to grow more corn. This will enhance the production of valuable protein products and feed produced as by-products of processing starch-containing corn grains as raw material. Therefore, to increase the corn production, conducting intensive research in connection with global warming and environmental conditions is necessary to introduce the exotic corn hybrids and technologies with high grain yield potential.

Global warming is gradually eroding food security throughout the world, especially in developing countries (Behnassi *et al.,* 2021). The world population could reach 9.8 billion by 2050 due to a rapidly growing nature, as well as, a projected significant increase in food demand (Valin *et al*., 2014). In this regard, feeding the growing population is a critical challenge facing humanity worldwide (Foley *et al*., 2011). Therefore, the search for optimal ways to provide the population with food consists with vertical increase in grain yield, which is possible through improving water-saving technology and the effective use of mineral fertilizers.

Currently, water deficit conditions are more than 20% in Kazakhstan; and in the future, as consumption increases, water resources will further decrease. Regarding this, water supply prospects in Kazakhstan's Southern and Southeastern regions, primarily reliant on transboundary waters, and deteriorating drainage systems and unstable structure of agricultural production, are particularly disturbing with global climate change, affecting more negatively Kazakhstan (Ibatullin, 2009). This situation poses a serious threat to the country's water supply and the intensification of desertification processes. In addition, the annual monitoring of irrigated lands conducted by hydro-geological and reclamation expeditions currently showed more than 50% of irrigated lands have varying degrees of salinity and more than 30% of soils are solonetzic. The massive volumes of drainage and wastewater generated on irrigated lands (30%–50% of water supply) and in populated areas (10%–30%) pollute the water sources and worsen the ecological and reclamation situation of irrigated lands and adjacent territories (Kvan *et al.*, 2011).

Numerous studies showed the most effective ways to rationalize the irrigation water through drip irrigation of crops, which approved the drip irrigation system as more efficient than other irrigation systems (Topak *et al.*, 2011; Kiymaz and Ertek, 2015). In drip irrigation fertigation, applying fertilizer to the active root zone also reduces the nutrient loss through leaching and evaporation (in the case of nitrogen) and increases fertilizer use efficiency (Singandhupe *et al.*, 2003). In drip irrigation, the utilization efficiency of nitrogen, phosphorus, and potassium has occurred to be 90%, 45%, and 80% compared to 30%–50%, 20%, and 50% through soil application, respectively (Raina *et al.*, 2013; Xu *et al.*, 2020). Better water and nutrient management also reduces the potential environmental risks associated with nutrient losses (Doszhanova *et al.,* 2023).

Currently, mini-till and no-till methods are the widely used resource-saving and moisture-saving technologies (Dridiger *et al.,* 2020; Zhapayev *et al.,* 2023a, b; Rzaliyev *et* *al.,* 2023; Kunypiyaeva *et al.,* 2023). The use of no-till technology in subsequent years increased the area to 205 million hectares worldwide (Mrabet *et al.,* 2022). In addition, the widespread use of zero tillage helped protect the soil from degradation and erosion and improve the soil ability to aggregate and reduce the greenhouse gas emissions compared with traditional technology (Krauss *et al.,* 2017).

Thus, the purpose of the past relevant studies was to determine the influence of different tillage regimes on water-physical properties of light chestnut soil under drip irrigation on corn crop. In this regard, the presented research sought to develop farming systems that ensure efficient use of water resources, increasing the productivity of irrigated arable land and corn crop, which is strategically vital, both on national and international scales.

MATERIALS AND METHODS

Study location and object

The field experiments, carried out in 2019–2021 on two maize (*Zea mays* L.) hybrids, commenced at the Kazakh Research Institute of Agriculture and Plant Growing LLP, Almalybak, Kazakhstan. The location sits on the foothill-irrigated zone of the Trans-Ili Alatau on light chestnut soils, using a multifactorial field experiment design (Table 1). The predecessor was the soybean crop. Field experiments employed two methods of soil cultivation in triplicate, and the placement of plots was systematic. The soil cultivation commenced with the depth of 25–27 cm by harrowing and pre-sowing, and the maize hybrids' sowing ensued in the last week of April, adding nitro ammophos at the rate of 300 kg/ha. The plot area was 50 m^2. The mineral fertilizers application continued as per the recommended package for Southeast Kazakhstan.

The studied mineral fertilizers included the following options against the background of additional application of nitro ammophosphate using fertigation: complex water-soluble mineral fertilizer Novalon containing 19% nitrogen, phosphorus, and potassium. Other contents comprised 2% magnesium and trace elements in chelated form (19-19-19 + 2MgO + ME), urea ammonium nitrate (UAN) containing nitrogen (32%), ammonium nitrate (200 kg/ha) based on three kg per ton of water. The Novalon, UAN-32, and ammonium nitrate applied by fertigation used a drip irrigation system during the vegetative period of corn plants at the phases of 4–5 leaves, sweeping, flowering, and grain filling. After plowing, low cultivation (leveling) continued—an obligatory element on regularly irrigated lands, then pre-sowing tillage. Combating weeds between rows and improving the soil aeration engaged a two-fold cultivation at the depth of 8–10 cm with a KRN-4.2 cultivator.

Following the maize field experiment scheme, moldboard plowing utilized a Grandtor reversible plow to a depth of 25–27 cm, with the sowing carried out with an Agromaster pneumatic precision seeder. Laboratory research, such as, analysis of the experimental soil and plants, proceeded in the accredited analytical laboratory of the Kazakh Research Institute of Agriculture and Plant Growing LLP. The object of research at the experimental site was the cultivation of corn hybrids for grains under drip irrigation. The hybrids were Tauelsizdik (Kazakhstan) and LG 30500 (France), with a seeding rate of 22 kg/ha.

Table 1. Scheme of field experiment to study cultivation methods, irrigation rates, and doses of mineral fertilizers for drip irrigation in corn.

Methods of basic tillage	Maize hybrids	Doses of mineral fertilizer application, kg, l per 1 ha
Moldboard plowing to a depth of 25–27 cm Zero tillage (No-Till)	Tauelsyzdyk (Kazakhstan), LG-30500 (France)	Nitro ammophos (300 kg/ha) - background Background + Novalon 19-19-19 + 2MgO + ME (10 kg/ha) Fon + CAS-32 (100 l/ha) (3 kg per 1 ton of water) Background + Ammonium nitrate (200 kg/ha)

Water supply to the drip irrigation system flowed through hydrants using the water flow energy. Corn hybrid seeds' treatment with the drugs fludioxonil + metalaxyl M + thiram was in accordance with the state standard, R52325-2005 DSTU 2240-93. The corn drip irrigation system included a water intake system connected to irrigation hydrants, a cleaning and fertigation system, main pipes, distribution pipes, and irrigation tapes for surface drip irrigation.

Research methodology

Studying the influence of soil tillage methods and drip irrigation systems on corn grain yield transpired in 2019–2021 at the inpatient laboratory of agriculture of the Kazakh Research Institute of Agriculture and Plant Growing, Almalybak, Kazakhstan. The soils of the experimental plot were foothill light chestnut soils with high carbonate content. According to the mechanical composition of the soil, it belonged to coarse-silty medium loams, with the content of physical clay at 39%–42%, coarse dust (45%–51%), and silt (12%–17%). The supply of soil with easily hydrolyzed nitrogen was average, available phosphorus was low, and exchangeable potassium was average. The upper horizon contains humus (2.02%) and gross nitrogen (0.12%–0.14%).

The field experiment arrangement, observations, and censuses progressed according to the methodology of Dospehov (1985). The determination of the water-physical properties of the soil followed the technique of Kachinsky (1970). Determining nitrates continued by the TsINAO method (GOST26488-85). Mobile phosphorus and potassium identification in carbonate soils began applying the approach of the Machigin method with modification of TsINAO.GOST26205-91. The yield data processing and compilation also relied on the procedure of Dospehov (1985).

Meteorological conditions

According to long-term weather data obtained from the meteorological station of the Kazakh Research Institute of Agriculture and Plant Growing, the average annual air temperature was +7.6 °C. The hottest month of the year was July, with an average monthly temperature of 24.1 °C. Stable snow cover developed in late November – early December and remained for 85–100 days. The sum of positive temperature during the active growing season of plants (April – September) reached 3429 °C. During the same period in the region, the precipitation ranged from 110.2 to 435.3 mm. According to long-term averages, the most precipitation falls during spring.

Meteorological conditions in 2019 differed significantly from the long-term average values, and the month of April turned out to be wetter (183 mm) and warmer than long-term indicators, especially the last 10 days (Table 2). Temperature indicators in May were, on average, below the level of long-term indicators. Precipitation fell twice less than the long-term average, and fell in the first 10 days of May, with the 20th and 30th days of May characterized by the lack of moisture.

Table 2. Average monthly air temperature and precipitation during the growing seasons.

Months	Precipitation (mm)				Air temperature (°C)			
	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
May	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

According to the temperature background, all summer months (June – August) were hotter than the long-term average by 1.1 °C–2.8 °C. Although precipitation was at or above the long-term levels, the same as in May, it fell 1–2 times at the beginning of the month. High temperature during the day and at night led to the appearance of air drought. The first 10 days of September were characteristic of heavy rainfall, the temperature background of 2.5 °C higher than the long-term average, and the precipitation was 67.2 mm. In total, 455.6 mm of precipitation fell during the corn-growing season, against 237.7 mm of the long-term average.

The meteorological conditions of 2020 were favorable for the growth and development of the corn plants. As in 2019, the month of April observed with a heavy rainfall (146.7 mm). One should note, for all five months during the corn-growing season, the precipitation exceeded the long-term average by 5.3–90.2 mm, except for June, observed below the long-term average by 11.3 mm.

According to the data, spring 2021 turned out to be wetter (88.9 mm) and warmer than the long-term average, especially in March, which was 3.4 °C higher. Precipitation in March contributed to the accumulation of sufficient moisture in the soil to produce vigorous corn shoots. Based on the temperature background, all summer months, except August, were hotter than the long-term average by 1.9 °C – 2.7 °C, and for precipitation, were 30.8 mm below normal. Agrometeorological conditions showed summer was extremely dry and hot. All these environmental factors influenced the growth and development of crops and, ultimately, their productivity.

RESULTS AND DISCUSSION

Agro-physical properties of soil

Soil density is one of the main indicators in studying the methods of basic tillage. In Southeast Kazakhstan, the physical condition of the soil in spring with the traditional method of tillage had the range of 1.17–1.18 g/cm^3, slightly higher with zero tillage (1.21–1.22 g/cm^3). During harvesting the soil density increases to a medium compact state, and with the traditional method of tillage (1.28–1.29 g/cm^3), slightly higher with zero tillage at 1.32–1.33 g/cm^3 (Zhapayev *et al*., 2023b). The results showed low soil density indicators on irrigated lands after corn sowing were visible with the traditional method of soil cultivation (1.17–1.22 g/cm^3), and with no-tillage (1.20–1.23 g/cm^3), depending on the year of research in the southeast of Kazakhstan (Table 3). Thus, the main tillage, due to better crumbling and a greater supply of plant residues into the cultivated layer, contributed to a slight decrease in soil density during traditional. In no-tillage, due to accumulated plant residues, contributed to the preservation of moisture reserves in the soil.

In soil structure, the optimal conditions emerged for the water, air, and thermal regimes, on which, the development of microbiological activity, the mobilization of nutrients, and their availability to plants depend. However, agronomically valuable and water-resistant aggregates largely determine

Table 3. Variations in agrophysical properties of light chestnut soil for corn depending on soil cultivation methods (2019–2021).

Years	Density (g/cm^3)		Agronomically valuable aggregates (%)		Water-resistant units (%)	
	Moldboard plowing	No-Till technology	Moldboard plowing	No-Till technology	Moldboard plowing	No-Till technology
2019	1.17	1.20	58	62	12.7	16.2
2020	1.20	1.21	66	73	10.8	11.9
2021	1.22	1.23	65	67	11.9	14.6

agricultural production characteristics and soil fertility level. Zhapayev *et al.* (2023a) reported the content of agronomically valuable aggregates (10-0.25 mm) resulted largely from soil cultivation methods and provided excellent structural conditions of the 0-30 cm layer during the growing season of crops (65%–69%) with dry sifting. The maximum content of structural aggregates was evident under sowing with zero tillage (69%), indicating the splendid aggregate state of the soil. However, the aggregates' minimum amount was apparent during plowing (65%). The content of water-resistant aggregates was the highest in the no-tillage variants, and with plowing, the water-resistant aggregates lessened to 20.8% in the crops.

In the latest experiments, under irrigation conditions, agronomically valuable aggregates were in the range of 62%–73%, indicating an excellent aggregate state of the soil, whereas with the moldboard plowing, it was only 58%–66% (Table 4). The content of water-resistant aggregates was the highest with zero tillage with varying indicators, ranging from 11.9% to 16.2%, while with moldboard plowing, the water stability of aggregates reduced to 10.8%–12.7% in the crops. This implied unsatisfactory water stability of the structure, as well as, insufficient stability of the soil composition as per its structure. The results revealed an urgent need to improve the structure of the studied soils, firstly, to increase the content of water-resistant aggregates in soils through increased grass sowing, mainly alfalfa, and the use of green manure and cover crops. Long-term research has established the structural and aggregate composition of the arable layer of the soil significantly affects the conditions of plant growth and the agrophysical properties of the soil, including its structure (Vorontsov and Skorochkin, 2019).

Agrochemical soil indicators

Traditional tillage often includes deep plowing, disc and harrowing, which greatly disturb the physical and agrochemical properties of the soil. However, with zero tillage, less soil disturbance was notable, and it increased the accumulation of plant residues, enriching the soil with nutrients and organic matter. Therefore, different methods of soil cultivation develop the different agro-ecological conditions for the growth and development of crops, such as, the availability of various nutrient content in accessible forms. Tillage improves the soil conditions for optimal germination, good growth, and yield (Khorami *et al.*, 2018).

Table 4. Variations in the nutrients' content in the soil during the corn-growing season (average for 2019–2021).

Options	Easily hydrolyzable nitrogen (mg/kg)			Mobile phosphorus (mg/kg)			Exchangeable potassium (mg/kg)		
	During sowing	Mid-growing season	Before cleaning	During sowing	Mid-growing season	Before cleaning	During sowing	Mid-growing season	Before cleaning
Moldboard plowing									
Nitro ammophos background	53	45	41	33	32	30	320	342	300
Background + Novalon	52	68	59	47	57	52	318	386	334
Fon + KAS-32	43	47	42	33	43	37	313	375	322
Background + Ammonium nitrate	54	63	53	37	42	32	328	394	309
No-Till technology									
Nitro ammophos background	54	52	45	40	42	35	331	349	315
Background + Novalon	53	61	56	50	58	55	322	390	352
Fon + KAS-32	50	55	52	47	51	45	320	382	332
Background + Ammonium nitrate	56	65	53	39	49	34	328	392	325

Initially, traditional soil cultivation improves the physical and chemical properties of the soil (Busari *et al*., 2015). However, due to the deterioration of the soil structure, no-tillage has replaced traditional tillage, which revealed excellent potential for sustainable production of agricultural crops without environmental pollution (Li *et al*., 2020).

As evaluation criteria, the indicators of mobile nutrient content (easily hydrolyzable nitrogen, mobile phosphorus, and exchangeable potassium) and the variations developed by these macronutrients in the soil during the growing season of corn were usable (Table 4). The easily hydrolyzed nitrogen content in the soil under corn sowing in early spring had the range of 43–56 mg/kg. However, by the end of the corn-growing season, it decreased to 41 mg/kg, and the same pattern manifested in mobile phosphorus and exchangeable potassium depending on the soil tillage and mineral fertilizers used. The use of nitrate nitrogen reserves from the beginning to the middle of the growing season of crops was 49%–70%, and in the middle of the growing season of crops, nitrogen decreased compared to its initial reserves (Okorkov, 2018).

The use of mineral fertilizers in all studied variants ensured an increase in the content of nutrients in the soil, and by the time of harvesting, the said content considerably decreased. Application by fertigation water-soluble mineral fertilizer Novalon helps maximize the content of easily hydrolyzed nitrogen (61 to 68 mg/kg), mobile phosphorus (47 mg/kg), and exchangeable potassium (386 to 300 mg/kg), in both moldboard plowing and zero tillage. In corn harvesting using all studied options of mineral fertilizers, a significant reduction was evident in the soil nutrient content against the background of ammonium nitrate. Optimization of water conditions during corn cultivation using drip irrigation system increased the grain yield by 28% on sandy soils, and in turn, the use of nitrogen fertilization under irrigation conditions increased the grain yield by 41% (Wu *et al*., 2019).

The main elements of productivity (the number of ears and grains) developed chiefly in the phases of 4–8 leaves, depending on the ripeness group, and then, the growth and development of plants occurs, ending with the phases of panicle flowering and ear formation. Reducing the undesirable effect of high temperature and low relative humidity, it was necessary to adjust the soil water regime. In the South and Southeast Kazakhstan conditions, the minimum factor was water, and the irrigation was more valuable in crop production. Irrigation water performs several functions. It maintains an optimal level of soil moisture and reduces the temperature by some degrees, also by developing a favorable microclimate in the ground layer, and increases the relative air humidity in corn agro-biocenoses. Drip irrigation and fertigation were treatments ensuring the stability of corn productivity over the years, contributing an increase in plant productivity by 25%, and in the dry season, more than 80% (Źarski and Kuśsmierek-Tomaszewska, 2023).

Additionally, mineral fertilizers are essential in drip irrigation. Different types of mineral fertilizers available in the market include the UAN-32, with the possibility of using ammonium nitrate. The additional use of mineral fertilizers, as well as, complex water-soluble fertilizer, helps to increase the corn grain yield from 0.87 to 2.68 t/ha with moldboard plowing, and from 1.55 to 2.85 t/ha with zero tillage (Table 5). Similarly, the maximum grain yield was prominent for the corn hybrid LG 30500 (12.95 t/ha) with moldboard plowing against the background of using nitro ammophos during sowing and the additional use of ammonium nitrate through fertigation. The study also notes ammonium nitrate has a high percentage of nitrogen in nitrate form, as directly absorbed by corn plants, and eventually, enhanced the grain yield. Since the grain yield depends on irrigation and nitrogen application methods in different ways, also demonstrating diverse reactions to different soil types, the net income from these management methods also varied depending on the years, treatments, and types of soil (Sharma and Irmak, 2020).

Table 5. Moisture content and grain yield of corn hybrids (average for 2019–2021).

Tillage types	Fertilizers							
	Nitro ammophos background		Background + Novalon		Fon + KAS-32		Background + Ammonium nitrate	
	%	t/ha	%	t/ha	%	t/ha	%	t/ha
Tauelsizdik								
Moldboard plowing	29.0	10.02	34.0	12.50	21.6	12.35	27.2	12.70
No-Till technology	21.9	9.00	27.0	11.00	22.6	11.25	29.2	11.85
LG 30500								
Moldboard plowing	25.5	11.80	24.9	12.67	28.6	12.80	28.1	12.95
No-Till technology	17.7	9.80	21.2	11.35	33.3	11.53	24.6	12.50

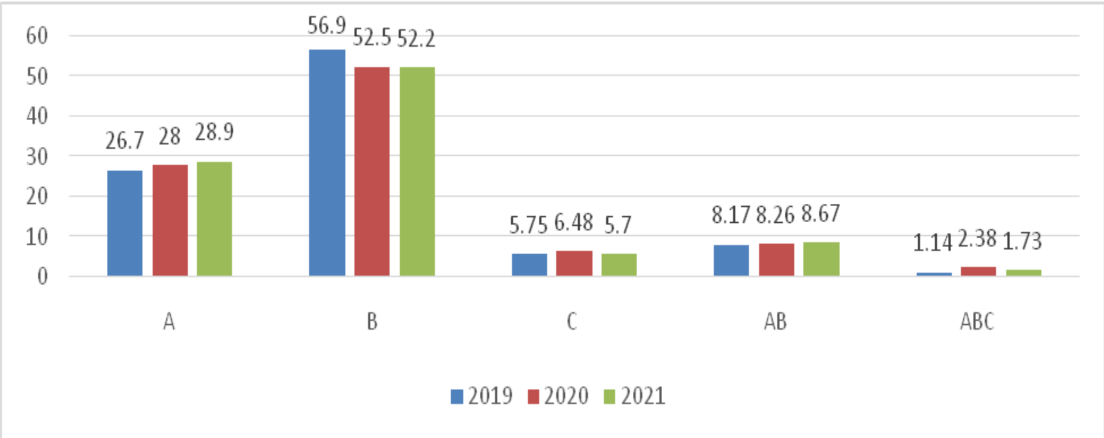

Figure 1. Two-way ANOVA of four different crops: A = Application of mineral fertilizers, B = Soil tillage methods, and C = Hybrids.

The recorded data processing by three-factor analysis of variance showed a significant influence of mineral fertilizers and soil tillage methods, as well as, an insignificant influence of hybrids and their interactions (Figure 1). However, the mineral fertilizers' contribution in the formation of corn grain yield was reliant on the year of research, ranging from 52.2% to 56.9%, share of soil cultivation methods (26.7% to 28.9%), hybrids (5.7%–6. 48%), and the share of interaction between the factors was 2.98% to 8.34%. One must note the formation of grain yield was largely dependent on the use of mineral fertilizers.

CONCLUSIONS

With drip irrigation, the additional use of mineral fertilizers and the complex water-soluble fertilizer, helps enhance the corn (*Zea mays* L.) grain yield from 0.87 to 2.85 t/ha. However, the maximum grain yield was evident in the corn hybrid LG-30500 (12.95 t/ha) against the background of nitro ammophos with additional use of ammonium nitrate by fertigation. Besides, the formation of corn grain yield depended, largely, on the use of mineral fertilizers. Their share of the contribution was dependent on the year of research, ranging from 52.2% to 56.9%.

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