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DIFFERENT TILLAGE REGIMES' EFFECT ON SOIL-WATER PHYSICAL AND AGROCHEMICAL PROPERTIES UNDER THE ENVIRONMENTAL CONDITIONS OF SOUTHEAST KAZAKHSTAN

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SUMMARY

For improvement and rational use of rainfed lands, a study on the influence of different tillage methods proceeded on the soil-water physical relationship and soil agrochemical properties in Southeast Kazakhstan. In the arable soil layer (0–30 cm), the soil density during the studied crop's life from sowing to harvesting, enhanced to a medium compacted state with the traditional method of tillage (1.28–1.29 g/cm^3), slightly higher with the minimum tillage (1.30–1.31 g/cm^3), and the highest with zero tillage (1.32–1.33 g/cm^3). Tillage with better crumbling, dissolution, and superior ingestion of plant vestiges in the cultivated soil layer contributed to a slight decrease in soil density, both with traditional and minimum tillage regimes. Given the least rainfall in summer, there was a decline in the productive moisture reserves in the soil with customary tillage (15.9–34.5 mm). However, the soil moisture enhanced gradually with reduced tillage, i.e., minimal tillage (20.7–36.7 mm) and zero tillage (29.8–54.8 mm). The nitrate nitrogen content in the soil also decreased from the initial state to the cultivated crops' harvest, and a significant decrease emerged with zero tillage. The prolonged rainless period, accompanied by a decline in relative air humidity, soil moisture, and temperature increases, affected plants' physiological processes and, eventually, the studied crops' yield. In the studied crops, on average, acquiring the highest yield of 1.76 t/ha was with minimal tillage. Based on two-way analysis of variance (ANOVA), the contributed share of the crops in the grain yield formation was according to crop season, ranging from 0.73% to 2.89%, and the soil cultivation methods' share was 83.3%–93.8%. The grain yield formation has a greater dependence on the tillage regimes, although that reliance might vary in association with weather conditions during the crop life. In rainfed conditions of Southeast Kazakhstan, zero tillage results in a significant reduction in nitrate nitrogen compared with conventional and minimum tillage. Therefore, with no tillage, more nitrogen fertilizer is necessary than usual plowing and the application of potash fertilizers, regardless of tillage methods.

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Keywords: Conservation agriculture, soil, traditional tillage, zero tillage, soil-water relationship, soil agrochemical properties, crop yield

Key findings: No-tillage results in a significant reduction in nitrate nitrogen in the soil, so no-till requires more nitrogen fertilizer application than conventional tillage. The formation of grain yield depended to a greater extent on the studied methods of soil cultivation, and the dependence only increased, which is associated with weather conditions during the growing season of the studied crops.

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INTRODUCTION

Global warming gradually intimidates food security worldwide, especially in developing countries (Werner *et al.,* 2018; Agboola and Bekun, 2019; Behnassi *et al.,* 2021; Pata, 2021). With its fast-growing nature, an expected world population will reach 9.8 billion by 2050 (United Nations, 2017), as well as, a projected significant increase in food demand (Valin *et al.*, 2014). In this regard, feeding the growing world population is humanity's foremost challenge to solve (Foley *et al.*, 2011). The search for optimal ways to provide the population with food is to increase crop yields vertically, which is possible through improving soil-protective tillage methods, conserving, and ensuring soil and water resources' efficient use, resulting in reduced greenhouse gas emissions. Among anthropogenic activities and events, agriculture is accountable for 12% of total greenhouse gas emissions (IPCC, 2014). It shows the vital role of agriculture and its management, particularly tillage, in reducing greenhouse gas emissions (WRI, 2014). Soil also stores 3–4 times more carbon than vegetation contains (Lal, 2004).

Long-term land exploitation (e.g., monoculture, over-cultivation, inadequate use of inputs, overgrazing, and burning of crop residues) (Ouassou *et al.*, 2006; Malek *et al.*, 2018), as well as, a low level of agricultural technology and management, led to a sharp decrease in soil fertility, including a significant organic matter reduction, which adversely affects soil properties decreasing crop yields (Ghimire *et al.*, 2017; Assemien, 2018; Sumberg and Giller, 2022). In addition, the land proportion used for agriculture is declining, especially in developing countries, due to urbanization and degradation. All this led to soil quality deterioration and decreased crop yields (Diaz-Ambrona *et al.*, 2005). The crop yield mainly depends on precipitation, especially during the crop-growing season. Therefore, rationally using rainfed lands in Southeast Kazakhstan requires switching to resource conservation and soil protection technology using drought-resistant crops. Under such conditions, improving farming systems based on soil-protective and resource-saving technologies is particularly significant (Kireev and Saparov, 2010).

Currently, resource-saving and moisture-saving technologies are widely used mini-till (minimum) and no-till (zero) methods (Gabbasova *et al.*, 2014; Korchagin *et al.*, 2014; Esaulko *et al.*, 2018; Dridiger *et al.*, 2020). In 2009, the global application of zero technology reached an area of about 111 million ha (Derpsch *et al.*, 2010), and in 2014, this number attained 155 million ha (Huang *et al.*, 2018). In succeeding years, the area has increased to 205 million ha worldwide (Mrabet *et al.*, 2022). Additionally, widely using zero tillage helped protect soil from degradation and erosion (Krauss *et al.*, 2017), improve soil aggregation capacity (Quiroga *et al.*, 2010), and reduce greenhouse gas emissions (Kong *et al.*, 2009) compared with traditional technology.

The first successful introduction and establishment of soil protection technology was with the cultivation of grain crops in Northern Kazakhstan (Karabaev *et al.*, 2005). According to FAO official data in 2009, Kazakhstan entered the list of top 10 countries using zero tillage technology in crop production from 1.5 million ha, increasing the area in 2014 to 2 million ha (Karabayev *et al.*, 2015), and by 2019, it has reached 3 million ha (Paukner, 2022). It is also notable that introducing these crop areas with zero technology was mainly in non-irrigated regions of Northern Kazakhstan. In 2012, Kazakhstan ranked first in Europe and Central Asia and seventh in the world with zero technology area. However, research on developing minimum and zero tillage technology has recently begun under rainfed conditions in Southeast Kazakhstan. Thus, the appropriate research purposed to determine the effects of various tillage regimes on the soil-water physical and agrochemical properties of light chestnut soil in Southeast Kazakhstan.

MATERIALS AND METHODS

Plant material and procedure

Source material screening in terms of their ability to most effectively use favorable environmental factors and, at the same time, withstand environmental stressors were the main conditions for selecting new cultivars (Katkov, 1999), and drought-resistant high-yielding crops that can grow throughout the country and their introduction is the most effective solution of the problems related to climate change and reduced precipitation.

For studying the various tillage regimes, field experiments were underway in the rainfed conditions of Southeast Kazakhstan. The objects of study were the methods of tillage (plowing with a depth of 20–22 cm, minimum tillage [with a depth of 8–10 cm], and zero tillage), and the studied crops were spring barley, peas, chickpeas, oil flax, and safflower. The laid-out field experiments had three tillage methods and three replications, and the placement of plots was systematic. Sowing of the studied crops proceeded on the third day of March, using a direct-sowing seeder Vence Tudo-7500 (Brazil), simultaneously introducing 100 kg of ammophos into the rows in the plot area of 125 m^2. Immediately after sowing in the fields of minimum and no-tillage, the chemical treatment with glyphosate-containing herbicide (3 L/ha) ensued to control all types of weeds. Before germination, in the experimental plots of safflower, the Dual Gold herbicide (1.5 L/ha) application prevented weeds, with the spring barley crop fields treated with Efir Premium herbicide (0.5 L/ha) in a tank mixture with a growth stimulator Beres 8 – 0.5 L/ha, the pea crop with Bazagran herbicide (3 L/ha), and the oil flax crop the herbicide Gerbitoks (1 L/ha) for weed control. In spring, at the 3-4 leaf stage, applying ammonium nitrate followed at the rate of 150 kg ha^{-1}.

Description of the study location

The experiments ran in 2021–2022 at the Stationary Laboratory of Agriculture, Kazakh Research Institute of Agriculture and Crop Production, Kazakhstan. The territory of Kazakhstan has characteristics of a wide variety of natural and climatic conditions, with 80% of cultivated lands located with insufficient moisture, including Southeast Kazakhstan's rainfed lands. In Southeast Kazakhstan, according to the annual rainfall, the division of rainfed lands comprised unsecured (with yearly precipitation from 200 to 280 mm), semi-provided (from 280 to 400 mm), and provided (over 400 mm), which is most acceptable. At the same time, the largest share of land falls under the unsecured rainfed zone (64%), with semi-secured and secured rainfed areas occupying 26% and 10%, respectively (Zhapayev *et al.*, 2023).

The soil cover of the experimental plot was piedmont light chestnut soils formed on forest-like loams and had a pronounced fertile profile. A characteristic feature of light chestnut soils was their high carbonate content; their frothiness was prominent from HCl from the surface. According to the mechanical composition of the ground, it belongs to coarse-silty medium loams, with physical clay (39%–42%), coarse dust (45%–51%), and silt (12%–17%). The soil provision with easily hydrolyzable nitrogen was medium, with low mobile phosphorus and medium exchangeable potassium. The upper horizon contains humus (2.02%) and gross nitrogen (0.12%–0.14%).

The tasks set started by laying and conducting field experiments and laboratory studies. Laboratory studies and the soil sample analysis transpired in the accredited laboratory of soil science and agrochemistry of the Kazakh Research Institute of Agriculture and Crop Production. Bookmarking the field experiment and conducting observations and counts was according to Dospekhov (1985). Assessing the soil-water physical properties followed the method according to 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.

Statistical analysis for comparing the treatments for various parameters continued employing a two-way analysis of variance (ANOVA). The treatment differences were significant when a value was $p < 0.005$.

Meteorological conditions

A characteristic feature of the climate at the foothill plains is its sharp continentality, large, daily, and annual fluctuations in air temperature, and unstable and insignificant amounts of precipitation. The main feature of the precipitation regime was the confinement of their maximum to the spring period and the minimum to the summer. Winter rainfall was 15%–25% of the annual amount, summer accounts for a little more than 20%, and the same amount for autumn. The maximum moisture reserves accumulate in the soil by the beginning of spring fieldwork. Spring is characteristic of thermal instability and frequent returns of cold weather. Autumn is long and relatively warm. Average daily values of relative air humidity in summer fall to 30%–34%. High temperature and low relative humidity promote intensive moisture evaporation.

According to long-term data from the meteorological station of the Kazakh 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. The temperature below 5 °C sets on either October 2 or 3. A stable snow cover forms in late November - early December and lies for 85–100 days. The sum of positive temperatures during the period of active vegetation of plants (April–September) reaches 3429 °C. The region's rainfall during the same period varies from 110.2 to 435.3 mm. According to long-term average data, the highest rainfall occurs in the spring.

During 2021, the meteorological conditions differed significantly from the long-term average values and were greatly varied (Table 1). According to the weather data, the spring of 2021 revealed more humid (88.9 mm) and warmer than long-term indicators, especially in March, described by an excess of long-term indicators by 3.4 °C. The March rainfall contributed to sufficient moisture accumulation in the soil to obtain friendly seedlings of the studied crops. Based on the temperature background, all the summer months, except August, were hotter than the average long-term indicators by 1.9 °C–2.7 °C, and on precipitation, it appeared below the norm by 30.8 mm. Agrometeorological conditions indicated the summer as extremely dry and hot. All these environmental factors affected the growth and development of the crop and, eventually, their yields.

During 2022, the meteorological conditions surfaced as a favorable year for obtaining high yields in the studied crops. According to weather data, the 2022 spring was wetter (by 193.9 mm) and warmer than long-term indicators. Rainfall in March and April contributed sufficiently to moisture accumulation in the soil to obtain friendly seedlings of the crops under study, and significant rainfall in May contributed to additional productive moisture accumulation in the ground. All the summer months in terms of temperature background, except August, were hotter than the average long-term indicators by 2.4 °C–3.1 °C, and rainfall was a deficit below the norm by 56.7 mm.

Table 1. Weather conditions for January–September 2021–2022 (Almalybak Weather Station, KazRIAPG LLP).

Months	Air temperature (°C)			Precipitation (mm)		
	2021	2022	long-term mean	2021	2022	long-term mean
January	-5.9	0.0	-10.8	14.1	16.3	19.8
February	1.8	0.8	-8.5	52.9	33.9	21.9
March	4.1	5.8	0.7	117.9	168.6	48.8
April	12.4	16.7	10.4	56.3	46.8	56.5
May	19.1	19.0	16.4	81.6	145.4	61.6
June	23.1	24.3	21.2	20.9	35.9	53.9
July	26.9	26.5	24.1	22.8	15.1	26.6
August	24.0	22.6	22.8	27.2	8.2	21.2
September	20.5	21.1	16.7	1.6	2.1	15.9
Average	14.0	15.2	10.3	395.3	472.3	326.2

Table 2. Soil density (g/cm^3) of light chestnut soil with different tillage methods.

Culture	Soil cultivation methods	After sowing			Before cleaning		
		2021	2022	average	2021	2022	average
Spring barley	Plowing 20–22 cm	1.18	1.17	1.18	1.27	1.29	1.28
	Minimum 8–10 cm	1.20	1.19	1.20	1.29	1.31	1.30
	Zero processing	1.21	1.21	1.21	1.32	1.32	1.32
Peas	Plowing 20–22 cm	1.17	1.16	1.17	1.28	1.29	1.29
	Minimum 8–10 cm	1.19	1.18	1.19	1.29	1.31	1.30
	Zero processing	1.21	1.21	1.21	1.33	1.32	1.33
Oilseed flax	Plowing 20–22 cm	1.18	1.17	1.18	1.28	1.28	1.28
	Minimum 8–10 cm	1.20	1.20	1.20	1.30	1.30	1.30
	Zero processing	1.22	1.22	1.22	1.32	1.31	1.32
Safflower	Plowing 20–22 cm	1.16	1.17	1.17	1.28	1.29	1.29
	Minimum 8–10 cm	1.19	1.20	1.20	1.30	1.31	1.31
	Zero processing	1.22	1.21	1.22	1.31	1.32	1.32

RESULTS AND DISCUSSION

Soil-water physical properties

Basic tillage is one of the ways to manage the soil structure and the soil-water-physical and agrochemical properties occurring in it, which significantly affect the environment and crop growth and yield. Tillage is a method that can be effective in reducing surface and subsoil compaction (Batey, 2009; Tullberg, 2010).

Soil density is one of the chief indicators in studying the different tillage methods during the growing season of crops. Similarly, in the chestnut soils of the dry steppe zone, varieties with acceptable values of equilibrium density (1.30–1.40 g/cm^3) are most common, while in the desert-steppe zone are light chestnut soils with allowable (1.35–1.45 g/cm^3) and critical values (>1.45 g/cm^3) equilibrium density (Kuznetsova *et al.*, 2011). From sowing to harvesting the studied crops, the soil density in the arable soil layer (0–30 cm) increased, regardless of the tillage methods. The results showed that after sowing, the lowest soil density resulted in the traditional way of tillage (1.17–1.18 g/cm^3), slightly higher with the minimum tillage (1.19–1.20 g /cm^3), and the highest at zero tillage (1.21–1.22 g/cm^3) (Table 2). In the spring, the physical state of the soil on the applied methods of tillage was visibly loose and slightly compacted. However, at harvesting, the soil density under the studied crops enhanced to a medium-compacted state with the traditional method of tillage (1.28–1.29 g/cm^3), slightly higher with the minimum (1.30–1.31 g/cm^3), and the highest with zero tillage (1.32–1.33 g/cm^3). Thus, due to better crumbling and greater intake of plant residues in the cultivated layer, tillage contributed to a slight decrease in soil density, both with traditional and minimum tillage.

Approximately 40% (600 million ha) of the world's arable land suffers from low rainfall, of which 60% are developing countries (Carbonell-Bojollo *et al*., 2019). Soil and moisture retention with an acceptable range improved crop growth and yields using no-till technology (Wang *et al.,* 2016). Zero tillage technology surface mulching enhances water infiltration and reduces water loss through evaporation (Jarecki and Lal, 2006). In addition, available soil moisture storage is imperative for better crop production in semi-arid regions, where crops mainly depend on soil moisture storage rather than seasonal rainfall (Dang *et al*., 2015).

The results further revealed that, on average and over two years, the productive moisture reserve in the soil was sufficient at the time of sowing, with traditional tillage (99.4–126.7 mm), minimum tillage (114.8–136.3 mm), and zero tillage (107.3–168.3 mm) to obtain friendly plant seedlings (Table 3). During the second day of May, the productive moisture reserve appeared to have decreased due to evaporation and transpiration by the studied crop plants. With less rainfall at the end of May, in June, and at the start of July, a further decrease occurred in the soil moisture reserves. By the beginning of harvest, the moisture amounted to 15.9–34.5 mm with traditional tillage, 20.7–36.7 with minimal, and 29.8–54.8 mm with zero tillage processing.

Agrochemical properties of the soil

Tillage improves soil conditions for optimum emergence, good growth, and yield (Khorami *et al.*, 2018). Initially, traditional tillage improved the physical and chemical properties of the soil (Busari *et al.*, 2015). However, with time, due to the deteriorating soil structure, no-till replaced traditional tillage, which revealed superior potential for sustainable crop production with no environmental pollution (Li *et al.*, 2020). Conventional tillage often includes deep plowing and disc harrowing, which critically disturbs not only the physical but also the agrochemical properties of the soil; no-tillage, on the other hand, has less soil disturbance, increases stubble accumulation, and enriches the soil with nutrients and organic matter (Veiga *et al.*, 2008). Moreover, the long-term application of no-till improves organic matter content and pore connectivity in the topsoil, enhancing the overall quality and fertility of the agroecosystem (Gajda *et al.*, 2018).

The nitrate nitrogen content significantly varies over the crop seasons, and the addition of ammonium nitrate (70 kg ha^{-1}) as a top dressing increased the nitrate nitrogen content (Gusev *et al.*, 2022; Kenenbaev *et al*., 2023; Makenova *et al*., 2023), while the higher availability of this nutrient in the soil, the less were the effect of fertilizers on this indicator. In the studied crops of the presented study, the nitrate nitrogen content in the ground at the initial state ranged from 25 to 53 mg/kg, which was very low with medium availability, and by the end of the growing season, it was 17–38 mg/kg (Table 4). In the studied soil, the mobile nutrient content decreases by harvest time of cultivated crops from the initial state, and a significant decrease was evident with zero tillage due to more consumption.

During non-moldboard cultivation, the decrease occurs in the nitrifying bacteria, reducing nitrate accumulation in the soil (Milashchenko *et al.*, 1979). Past studies authenticated this phenomenon by the intense immobilization of plant residues and deterioration of aeration conditions due to soil compaction (Bazdyrev, 1990; Okorkov *et al.*, 2020). At the same time, the coefficient of use of the initial reserves of nitrate nitrogen until the middle of the growing season of crops was 49%–70%. It also has proof by the decrease in the supplies of these forms of nitrogen in the middle of the growing season of crops compared with its initial stocks (Okorkov *et al.*, 2017; Okorkov, 2018). The higher use of nitrate nitrogen by crop plants was due to their complete presence in the soil's liquid phase (Okorkov *et al.*, 2020).

Thus, the available nitrate nitrogen was minimum and medium at the growing season's end of the studied crops. Introducing phosphatic fertilizer was also feasible by

Table 3. Productive moisture reserve (mm) with different tillage methods in a meter layer of soil.

Culture	Soil cultivation methods	Seedling phase			Before cleaning		
		2021	2022	Average	2021	2022	Average
Spring barley	Plowing 20–22 cm	77.3	121.5	99.4	37.4	15.5	26.5
	Minimum 8–10 cm	98.4	131.2	114.8	29.7	18.8	24.3
	Zero processing	107.2	107.3	107.3	42.7	22.6	32.7
Peas	Plowing 20–22 cm	112.5	136.8	124.7	35.8	18.0	26.9
	Minimum 8–10 cm	128.1	140.0	134.1	51.4	21.9	36.7
	Zero processing	137.1	183.2	160.2	57.5	43.7	50.6
Linen	Plowing 20–22 cm	103.2	111.6	107.4	49.2	19.7	34.5
	Minimum 8–10 cm	112.1	142.0	127.1	50.6	11.2	30.9
	Zero processing	104.2	160.7	132.5	64.3	45.3	54.8
Safflower	Plowing 20–22 cm	110.2	143.2	126.7	20.0	11.8	15.9
	Minimum 8–10 cm	132.5	140.0	136.3	28.9	12.4	20.7
	Zero processing	139.2	197.4	168.3	42.9	16.6	29.8

Table 4. The mobile nutrients content (mg/kg) in light chestnut rainfed soil with different methods of basic tillage during 2021-2022.

Culture	Soil cultivation methods	Nitrate nitrogen		Mobile phosphorus		Exchangeable potassium	
		Original content	Before cleaning	Original content	Before cleaning	Original content	Before cleaning
Spring barley	Plowing 20–22 cm	25	17	29	30	292	226
	Minimum 8–10 cm	27	38	25	36	272	248
	Zero processing	53	32	35	55	312	278
Peas	Plowing 20–22 cm	31	27	21	23	289	189
	Minimum 8–10 cm	25	22	23	28	273	218
	Zero processing	49	33	38	59	334	250
Oilseed flax	Plowing 20–22 cm	28	29	28	53	301	239
	Minimum 8–10 cm	30	27	24	29	285	239
	Zero processing	44	25	36	57	358	315
Safflower	Plowing 20–22 cm	27	27	28	52	308	243
	Minimum 8–10 cm	28	23	28	52	298	286
	Zero processing	45	32	31	32	320	271

increasing the soil's mobile phosphorus content equal to the initial value (21–35 mg/kg) during harvesting the studied crops. Its amount in the soil increased from the initial state to the harvest of cultivated crops ranging from 23 to 59 mg/kg and was medium, high, and very high supply. Concerning exchangeable potassium content in the soil with various methods of primary treatment, notably, there was a decrease in its amount from the initial state in the land (272–358 mg/kg) at the end of the crop season. Before crop harvesting, the soil's exchangeable potassium content ranged from 189 to 315 mg/kg, providing a low, medium, and high degree. Thus, no-tillage results in a significant reduction in nitrate nitrogen compared with conventional and minimum tillage. Therefore, using no-tillage requires more nitrogen fertilizer than with conventional tillage. In addition, it is necessary to use potash fertilizers, regardless of the tillage regimes.

Grain yield

Increasing crop yields is the sole aspect of achieving future food security goals, and on agriculture sustainability, intensive traditional production methods can have severe negative environmental impacts (Foley *et al.*, 2011; Godfray and Garnett, 2014). The maximum dissemination of zero tillage technology

Table 5. Grain yield of the studied crops with different tillage methods (t/ha).

Culture	Soil cultivation methods								
	Plowing by 20–22 cm			Minimum tillage			Zero tillage		
	2021	2022	Average	2021	2022	average	2021	2022	average
Spring barley	1.24	4.86	3.05	1.67	4.99	3.33	1.44	3.72	2.58
Peas	0.45	2.99	1.72	0.43	3.03	1.73	0.45	3.13	1.79
Linen	0.80	0.99	0.90	0.65	1.1	0.88	0.68	1.15	0.92
Safflower	0.71	1.05	0.88	1.09	1.1	1.10	1.16	1.00	1.08
Average	0.80	2.47	1.64	0.96	2.56	1.76	0.93	2.25	1.59
$LSD_{0,05}$	2021 = 0.19, 2022 = 0.49								

occurred in the mid to late 1990s worldwide, aided by herbicide use and advanced zero technology (Derpsch *et al.,* 2010). No-till shows the best results in rainfed conditions in arid climates; however, after the no-till introduction and in the first two years, it decreased for all crops (Pittelkow *et al.,* 2015).

The 2021 dry summer caused severe damage to Kazakhstan, and overall agriculture suffered many losses. A prolonged rainless period, accompanied by a decrease in relative air humidity, soil moisture, and temperature increase, adversely affected the physiology of crop plants and, subsequently, the studied crops' yield. The grain yield of the studied crops ranged from 0.43 to 1.67 t/ha (Table 5). On average, the highest produce was notably with minimal tillage amounting to 1.76 t/ha.

In the spring of 2022, the rainfall was 193.9 mm more than long-term indicators; especially in March, the precipitation was 168.6 mm, and the weather was warm, characteristic of an excess of long-term indicators by 4.6 °C. The grain yield of the studied crops ranged from 0.57 to 4.99 t/ha. The highest grain yield was evident with minimal tillage of spring barley at 4.99 t/ha, and with traditional and minimum tillage, the harvests were 4.86 and 3.72 t/ha, respectively. In semi-arid regions, the crop yield depends more on the rainfall during the growing season than on its total amount (Pala *et al.,* 2000; Sarker *et al.,* 2003; Tafoughalti *et al.,* 2018; Zhang *et al*., 2015).

According to past studies, zero tillage stabilizes the yield over the years, and it takes at least 4–6 years to realize the potential (He *et al.,* 2011; Govaerts *et al.,* 2005; Keil *et al.,* 2020). From other sources, the grain yield with zero tillage compared with plowing decreased significantly in the first years; by the sixth to the seventh year, it tended to reduce, and by the ninth year, even some of its advantage was prominent (Polyakov, 2021). In addition, the moisture status during the growing season of crops largely determined a slight increase in soil density and not by the tillage regimes.

Data processing with a two-way analysis of variance showed a significant influence of the studied crops, tillage methods, and the interaction of crops and tillage methods (Figure 1). However, the contributing share of crops to grain yield formation, depending on crop season, was within 0.73%–2.89%, with the soil tillage methods' share being 83.3%–93.8%, and the share of the interaction effects was 2.98%–8.34%. Notably, the grain yield formation, to a greater extent, depended on the tillage regimes; however, that dependence only increased in association with environmental conditions during the growing season of the studied crops.

CONCLUSIONS

The zero tillage results in a significant reduction in nitrate nitrogen compared with conventional and minimum tillage under the rainfed conditions of Southeast Kazakhstan. Therefore, with zero tillage, more nitrogen fertilizer is necessary than traditional tillage, as well as, the application of potash fertilizers, regardless of tillage regimes. Grain yield formation, to a greater extent, depended on the tillage methods, with the dependence increasing in association with weather conditions during the growing season of the studied crops.

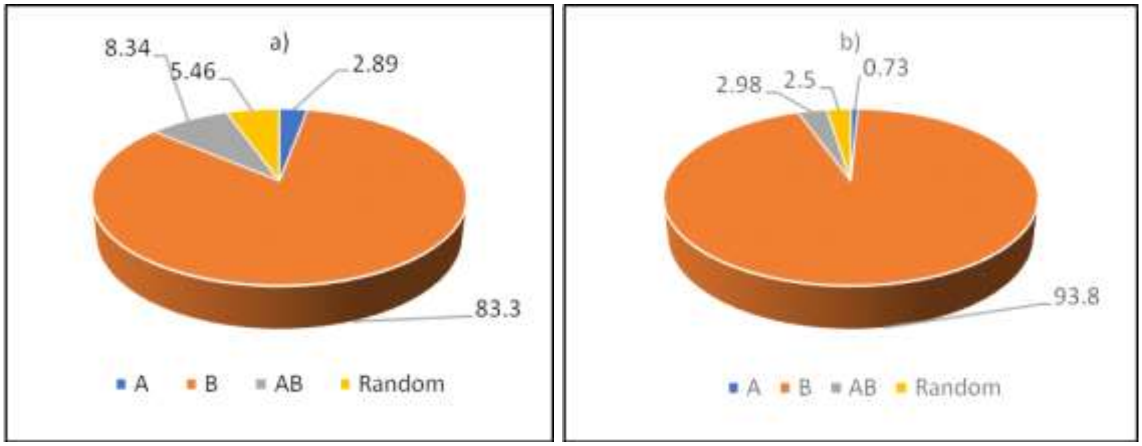

Figure 1. Two-way ANOVA of four different crops: a) 2021, b) 2022, where: A = Crops, B = Soil tillage methods, and AB = Interaction of crops and soil tillage methods.

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