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SOIL CULTIVATION METHODS' IMPACT ON SOIL WATER-PHYSICAL PROPERTIES UNDER RAINFED CONDITIONS OF SOUTHEAST KAZAKHSTAN

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SUMMARY

For the rational use of rainfed lands in Southeast Kazakhstan, the practical study aimed to determine the influence of different cultivation methods on the water-physical properties of the soil. The results revealed that, on average, for two years, the reserve of productive moisture in the ground during the spring with plowing at 20–22 cm was 127.8–146.4 mm, with minimal tillage at 8–10 cm (132.3–157.0 mm), and with zero tillage (122.2–140.8 mm) for all studied crops. With insufficient rainfall in summer, the moisture reserve decreased to 21.5–26.2 mm with plowing, 23.5–28.0 mm with minimal tillage, and 27.8–37.6 mm with zero tillage. In the studied crops, the soil density in the arable soil layer (0–30 cm) showed significant variations depending on the methods of soil cultivation. In spring, the soil was in a loose and weakly compacted state (1.17–1.22 g/cm^3), and during harvesting, it increased and became dense (1.29–1.32 g/cm^3), especially with zero tillage. Soil tillage methods provided the best structural aggregate condition (58%–71%) during the growing season of the studied crops of agronomically valuable aggregates (0.25–10 mm). However, the maximum content of structural aggregates (69%–71%) was evident with zero tillage by sowing safflower, spring barley, and Sudan grass. It indicates the excellent aggregate state of the soil under natural conditions with these crops. However, its minimum amount (58%) occurred with plowing (20–22 cm) under safflower. The water-resistant aggregate content was highest in no-tillage variants of the studied crops, varying between 17.6%–18.9%. With plowing, the water resistance of aggregates decreased to 13.1% under different crops. Over two years of research, the highest average yield of spring barley (2.42 t/ha) emerged with minimal tillage, while the lowest grain yield of Sudan grass (0.67 t/ha) came from plowing. As a result, the highest grain yields of spring barley, peas, and safflower emanated with minimal tillage, while in the Sudanese grass, with zero tillage.

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Keywords: Conventional tillage, minimal tillage, no-tillage, soil structure, spring barley, peas, safflower, Sudan grass, crop yield

Key findings: The introduction of minimal tillage into production on the rainfed lands of Southeast Kazakhstan increased the grain yield of spring barley, peas, safflower, and Sudanese grass while preserving the supply of productive moisture in the soil. The formation of grain harvest largely depended on weather conditions during the growing season of the studied crops.

INTRODUCTION

Long-term soil exploitation with a low level of agricultural technology has led to a severe decrease in soil fertility, and allegedly, soils have lost a higher amount of humus (30%) compared with the humus level in the 1950s. Decrease in humus content (Kogut *et al.*, 2019), deterioration of the soil structural condition (Kholodov *et al.*, 2016, 2019), and a decrease in other soil properties directly affect plants' health and productivity.

In the last few decades, climate change has been causative with uneven precipitation and wider fluctuations in temperatures due to increasing concentrations of CO_2 in the atmosphere. In this regard, one of the foremost tasks is to preserve and boost soil fertility in modern agriculture and enhance crops' productivity (Raimanova, 2010; Sabitov *et al.*, 2016; Kuzychenko *et al.*, 2021). For properly regulating various soil processes, soil fertility management relies on using varied methods of soil cultivation, which generate optimal conditions for the crop plant's life.

Different crops' cultivation consumed mineral and organic substances, deteriorating the water, air, and phytosanitary conditions. With tillage, the most vital agrotechnical activity in the farming system remains, determining the plant's water, air, and mineral nutrition and significantly affecting the field crop's productivity (Kuzina, 2015; Kuzina and Yakunin, 2016). An integral part of soil fertility contained in the agro-physical properties of the soils also determines the soil's mechanical properties and directly persuades all the factors of plant life.

Thus, the development of the agrobiocenosis massif depends on the geobotanical map of the region (Alibek et *al.*, 2020). For thousands of years, people have utilized plants as a means of treating illness, having given them particular consideration in addition to their nutritional significance. Numerous untamed plants possess abundant natural resources; however, the swift depletion of forest areas due to human activity, haphazard construction, and overuse of domesticated plants leads not only to a reduction in their quantity but also to the demise of numerous natural species (Ydyrys *et al.*, 2020), a reduction in the variety of species (Seilkhan *et al.,* 2016; Seilkhan *et al.,* 2018), as well as the endemism crisis (Akhmetova *et al.,* 2018; Ydyrys *et al.,* 2020). Growing medicinal plants in agricultural fields or botanical gardens is therefore a different approach to acquiring more raw materials (Bukenova *et al.,* 2019; Yeszhanov *et al.,* 2020).

The most favorable conditions for the growth and development of crop plants were on soils of medium granulometric composition (Volters *et al.*, 2022). Hence, current agriculture faces an acute problem of reducing cultivation's adverse effects on soil fertility. In this regard, it is necessary to reasonably use the land under different crops and increase soil fertility to obtain sustainable crop yields and the highest gain per unit area with the lowest cost of production. The mentioned soil issues may be well-managed using minimum and zero tillage, which are more economical than costly plowing.

In the present era, several studies have evolved on the possibility of restoring and preserving the soil fertility of arable layers during the transition from a traditional farming system with moldboard cultivation to soil conservation technology, including the use of cover crops (Ospanbayev *et al.*, 2023). The most promising soil process includes minimum and zero tillage and direct sowing of different crop plants, widely used worldwide on around 205 million hectares (Mrabet *et al.*, 2022). In addition, no-till also helps reduce soil erosion and dehumidification, improving its physical properties, increasing biological activity and fertility, and consequently, the ecological conditions of the soil (Jordan *et al.*, 2010; Kislov *et al.*, 2018; Zavalin *et al.*, 2018). Zero tillage also saves the available resources and raises agriculture's profitability with low production costs (Rosner *et al.*, 2008; Dridiger *et al.*, 2017; Safin, 2020).

Evidence of the advantages of technologies with minimal tillage methods compared with classical plowing has yet to flourish. Therefore, before moving on to their widespread induction into production, further study of various systems of basic tillage and their adaptation to specific soil and climatic conditions is necessary. Thus, the study of the agrophysical properties of soils is very crucial and can be a vital component of fertility. In this regard, the presented research strived to determine the influence of various soil cultivation methods on the agrophysical properties of the soil, such as soil density, productive moisture reserves, and the structural and aggregate composition of the land in the arid zone of Southeast Kazakhstan.

MATERIALS AND METHODS

Plant material

Field experiments to study the impact of different methods of soil cultivation transpired in rainfed conditions at the Experimental Field of the Kaskelen Agropark in Southeast Kazakhstan (43°17′12.48″N, 76°41′48.48″E). The objects of study were the three different methods of soil cultivation (plowing at a depth of 20–22 cm, minimal tillage at a depth of 8–10 cm, and zero tillage) using crops such as spring barley (variety Symbat), peas (variety Zhasylai), safflower (variety Nika 80), and Sudanese grass (Kazakhstan 3) grown in the semi-sufficient rainfed conditions of Southeast Kazakhstan.

Conducting the field experiments used three soil cultivation methods in three replicates, with the systematic placement of experimental plots. Sowing of the studied crops proceeded at the end of March, using the direct-sowing seeder, Vence Tudo-7500 (Brazil), with simultaneous application of 100 kg of ammophos into the rows, and the area of the experimental subplot as a variant was 750 m^2. Immediately after sowing, chemical treatment with glyphosate-containing herbicide at the rate of 3 L/ha ensued against all types of weeds on the minimum and zero-tillage crops. Against weeds on the experimental plots, application of the following treatments comprised: safflower crops with the herbicide Dual Gold (1.5 L/ha) before germination; during the growing season the spring barley crop with the herbicide Ether Premium (0.5 L/ha) in a tank mixture with growth stimulant Beres 8 (0.5 L/ha); on pea crops with the herbicide Bazagran (3 L/ha); on oilseed flax with the herbicide Herbitox (1 L/ha); and Sudanese grass with the herbicide Ballerina (0.4 l/ha). After the seedling emergence, fertilizing with ammonium nitrate progressed at 150 kg ha^{-1}.

Meteorological conditions

The climate in the foothill plains was sharp continental, with large daily and annual air temperature fluctuations and unstable and insignificant amounts of rainfall. The main features of the precipitation regime are that maximum downpours are confined in the spring period, while the minimum shower occurs in the summer. Winter precipitation accounts for 15%–25% of the annual amount, while summer accounts for slightly more than 20%, with the same amount for autumn precipitation. In the soil, the maximum moisture reserves formation began during the fieldwork in spring, a season characterized by thermal instability and frequent returns of cold weather. Autumn is long and relatively warm. Average air daily relative humidity in summer drops to 30%–34%. High temperature and low relative humidity promote intense evaporation of the soil moisture.

Table 1. Meteorological conditions for the months of January–September, years 2021–2022, weather station Almalybak, LLP KazRIAPG.

Month	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
For nine months	14.0	15.2	10.3	395.3	472.3	326.2

In 2021, the meteorological conditions differed significantly from the long-term average values, characterized by great diversity (Table 1). According to weather data, the spring of 2021 was wetter (by 88.9 mm) and warmer than long-term indicators, especially in March, with an excess of 3.4 °C compared with long-term gauges. Rainfall in March contributed to sufficient moisture accumulation in the soil to obtain vigorous shoots of the crops under study. All the summer months in terms of temperature background, except for August, were hotter than the long-term average by 1.9 °C–2.7 °C, and on precipitation, it was 30.8 mm below normal. According to agrometeorological conditions, summer was super dry and hot. All these factors affected the growth and development of the crop plants grown in that area.

The year 2022 had favorable meteorological conditions for obtaining high yields of the crops under study. Spring was wetter (by 193.9 mm) and warmer than long-term indicators. Precipitation in March and April contributed an adequate moisture accumulation in the soil to acquire vigorous shoots of the studied crops. A significant amount of rainfall in May contributed to an additional productive moisture accumulation in the ground, contributing to further growth and development of the crops. All summer months in terms of temperature background, except for August, were hotter than the long-term average by 2.4 °C–3.1 °C and there was a precipitation deficit below normal by 56.7 mm. According to agrometeorological conditions, the summer period was acutely dry and hot; however, the spring rainfall increased moisture accumulation in the soil, ultimately affecting the studied crops' yield.

Study area description

The Kazakhstan territory is characteristic of a wide range of natural and climatic conditions, with 80% of cultivated lands located in insufficient moisture zones, including rainfed lands in Southeast Kazakhstan. According to the annual precipitation, absolute height above sea level, and the amount of total radiation in Southeast Kazakhstan conditions, it is customary to divide rainfed areas based on yearly rains into three categories, i.e., unsecured (200 to 280 mm), semi-secured (from 280 to 400 mm), and secured (over 400 mm) areas. Similarly, the maximum area share falls under unsecured rainfed land (64%), while semi-secured and secured rainfed lands occupy 26% and 10%, respectively (Zhapayev *et al.*, 2023a). In this regard, there is a need to study various methods of soil cultivation.

In crop production, tillage is one of the most energy-intensive processes. It is the most expensive and complex operation, organizationally slow, fuel-demanding, labor-intensive, and environmentally unfavorable in crop production (Stajnko *et al.*, 2009). Relatedly, the presented research on the study of various methods of tillage, including zero tillage in light-chestnut soils, commenced in

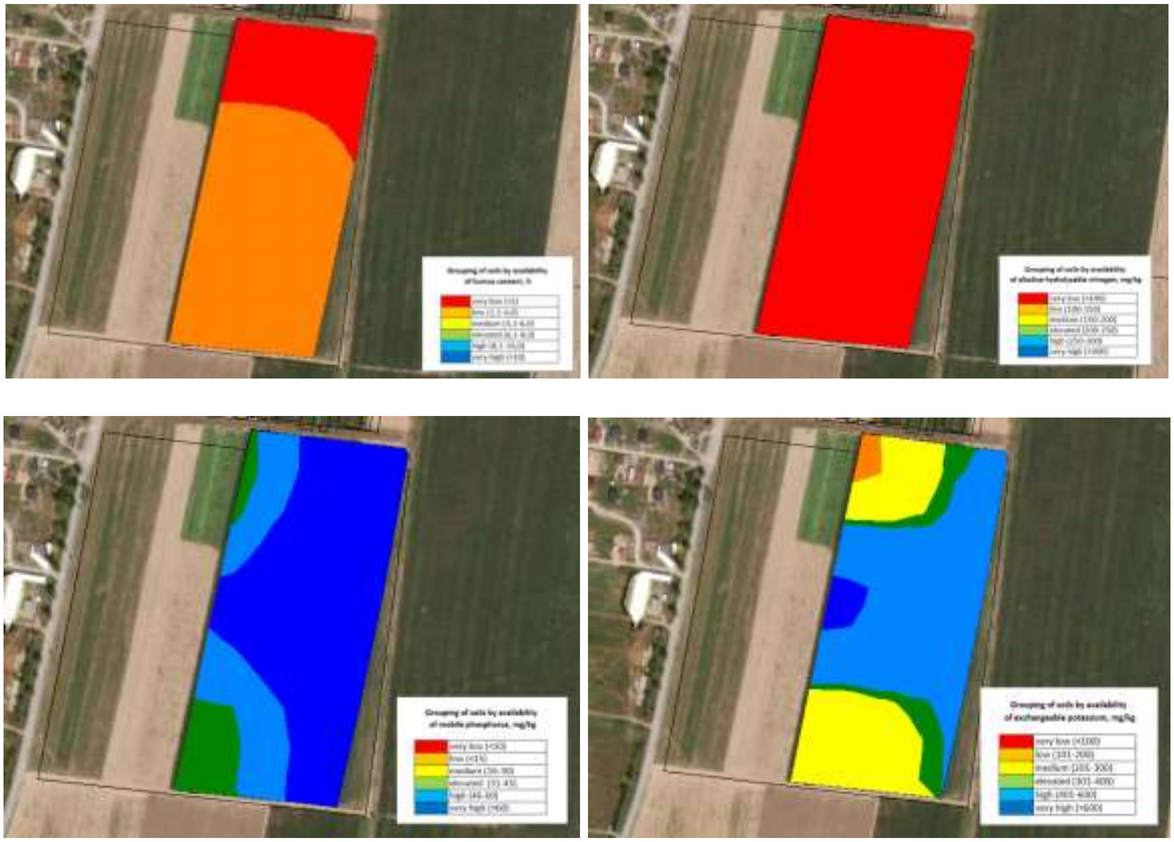

Figure 1. Cartogram for the supply of nutrients in the soil.

2021–2022 at the Experimental Field of the Kaskelen Agropark of the Kazakh Research Institute of Agriculture and Plant Growing under the rainfed conditions of Southeast Kazakhstan (Figure 1). The experimental soil has a humus content of 2.09%, a minimum content of alkali-hydrolyzable nitrogen (85 mg/kg), and increased content of phosphorus (64.7 mg/kg) and potassium (459 mg/kg). The studies ran with the background of nitrogen-phosphorus fertilizers (N35:P50). Mineral fertilizers P50 (ammophos) application ensued during sowing while applying N35 in the spring after germination.

Solving the assigned problems pursued setting up and conducting field experiments and laboratory studies. Soil analysis and other laboratory studies materialized in the Accredited Laboratory of Soil Science and Agrochemistry, Kazakh Research Institute of Agriculture and Plant Growing, Kazakhstan. The arrangement of the field experiment, observations of various parameters, and the censuses proceeded according to the method of Dospekhov (1985). Determining the water-physical properties of the soil followed the guidelines of Kachinsky (1970). Statistical analysis based on two-factor analysis of variance (ANOVA) of the treatments for various parameters and the treatments' differences incur comparison and separation through the $LSD_{0.05}$ test.

RESULTS AND DISCUSSION

Soil tillage methods are the chief factor in improving the culture of crops and enhancing crop yields. The agrophysical properties of the soil depend upon it, also determining the soil climate's water-air conditions and the degree and depth of incorporation in plant residues. In addition, the tillage methods also determine the structure of the soil profile based on the sharing of solid phase particles, nutrient reserves, and the interchange of carbon dioxide and moisture. All these can also influence the dynamics and ratio of humus mineralization, the formation of mobile nutrients, and their absorption by crop plants. The structural composition of different soils consists of elementary particles, which, in their natural state, incur combining into a complex system of macro- and micro-aggregates.

Soil moisture

Soil moisture and atmospheric humidity affect crops' productivity during the growing season. As previously noted in the arid zone, considerable performance was evident by cultivating crops under no-till technology (Volters *et al.*, 2022). The mulch on the soil surface retains moisture from evaporation, improving its infiltration and making it available to plants during dry episodes in the growing period, especially in rainfed zones (Mrabet, 2011)*.* In this regard, the supply of productive moisture was well-defined in the spring after sowing and in the summer after harvesting the crops under study.

The latest investigations showed that, on average, for two years in the soil during the spring, the productive moisture reserve was sufficient, with plowing at 20–22 cm was 127.8–146.4 mm for all crops, with minimal tillage at 8–10 cm (132.3–157.0 mm), and with zero tillage (122.2–140.8 mm). Given the insignificant amount of precipitation at the end of May, in June, and at the beginning of July before harvesting, a decrease in the moisture reserves was apparent for all soil variants and the studied crops due to evaporation and transpiration by plants, amounting to 21.5 cm by plowing at 20–22 cm (26.2 mm), and with minimal soil processing and tillage of 8–10 cm (23.5–28.0 mm).

Soil density

Soil density is an indicator of the agrophysical conditions of the soil, on which the plant's growth and development and crop productivity depend. However, it must be within certain required limits, called the optimal range. The optimal soil density range for most of the crops in loamy soils has a score between 1.00–1.30 g/cm^3, and as the total humus content shows a decline, the optimal density also shifts towards compaction (Kurachenko *et al.*, 2018). The soil density mostly depends on the soil cultivation and tillage methods, with that phenomenon as an active focus for several scientists in their past studies on tillage and direct seeding and agrophysical properties of chernozems and field crop yields (Polyakov, 2021). In addition, zero tillage, with a long-term refusal of basic tillage, promotes the formation of plant mulch, serving as an analog of litter from plant litter.

In the presented experiments, determining the density of light chestnut soil for the studied crops in the arable soil layer (0–30 cm) and the soil layers of 0–10, 10–20, and 20–30 cm showed significant variations, both in the above layers and based upon the cultivated crops. In the pertinent study, there was a tendency to enhance the level of optimal soil density in the spring after sowing and before harvesting all the crops. During spring, the soil under the studied crops was in a loose and weakly compacted state (1.17–1.22 g/cm^3), and by the time of crop harvest, its density increased and became dense (1.29–1.32 g/cm^3), especially with zero-tillage soils (Table 2). In spring, the soil's loose state was visible with plowing at 20–22 cm for the studied crops, with the range of 1.17–1.18 g/cm^3, spacious and slightly compacted with minimal tillage at 8–10 cm (1.19–1.20 g/cm^3), and slightly compressed with zero tillage (1.21–1.22 g/cm^3). However, an increase in soil density also manifested from the germination phase to crop harvest, with plowing by 20–22 cm, from a loose state to a medium compacted state (1.28–1.29 g/cm^3), with minimal tillage, from a movable and weakly compacted structure to a medium condensed (1.30–1.31 g/cm^3), and zero tillage, from slightly to highly compacted (1.31–1.32 g/cm^3) (Table 3). The results were also in analogy with past findings on ecological sustainability of agrocenoses and by introducing no-till technology in winter wheat and rye crops (Volkov *et al.*, 2020; Ramazanova *et al*., 2023).

Table 2. Total productive moisture in a meter layer for different methods of soil cultivation (mm).

Culture	Processing methods	In spring			Cleaning		
		2021	2022	average	2021	2022	average
Spring barley	Plowing	113.3	156.3	134.8	26.4	25.9	26.2
	Minimal processing	93.5	171.0	132.3	34.7	21.3	28.0
	No-till	115.5	139.8	127.7	32.8	42.3	37.6
Peas	Plowing	124.6	156.8	140.7	25.4	21.9	23.7
	Minimal processing	135.5	178.5	157.0	28.5	18.5	23.5
	No-till	116.0	132.5	124.3	30.5	25.0	27.8
Safflower	Plowing	92.5	163.1	127.8	19.2	28.6	23.9
	Minimal processing	137.7	155.5	146.6	24.6	24.7	24.7
	No-till	110	134.4	122.2	29.5	41.8	35.7
Sudan grass	Plowing	147.8	144.9	146.4	24.2	18.8	21.5
	Minimal processing	118.7	162.6	140.7	35.9	17.7	26.8
	No-till	133.9	147.6	140.8	39.5	35.7	37.6

Soil density on chestnut soils of the dry steppe zone had the most common differences recorded with the acceptable values of equilibrium density (1.30–1.40 g/cm^3) (Kuznetsova *et al*., 2011). According to Kazakov (1997), in dry seasons, the optimal density was higher for wheat (ranging from 1.00–1.20 g/cm^3), while in wet seasons it was lower by 0.10 g/cm^3. However, if the soil density exceeds 1.20–1.23 g/cm^3, pores and aeration become less, while the optimal soil density for grain on Southern carbonate chernozems was 1.05–1.2 g/cm^3 (Vasiliev and Revut, 1965;). According to Revut (1969) and Nechaev *et al.* (2009), the discrepancy between soil density and agro-biological requirements of the crops leads to a significant decrease in grain yield. Therefore, when the equilibrium density does not exceed 1.23 g/cm^3, the exchange of gases does not deteriorate even with zero tillage (Kazakov, 1990).

Structural conditions of the soil

The structural state of the soil determines the conditions of water, air, and thermal regimes, which, in turn, determines the development of microbiological activities and the mobilization of nutrients and their availability to crop plants. Several past studies have established that the structural and aggregate composition of the arable layer considerably affects the growth and development of plants; it also alters the agrophysical properties of the soil, including its structure (Vorontsov and Skorochkin, 2019). Agronomically, the cloddy-grained composition with aggregate sizes ranging from 0.25 to 10 mm is more valuable, having porosity and water resistance; such a structure determines the most favorable water-air regime of the soil (Nebytov, 2005; Zhapayev *et al*., 2023b).

During dump cultivation, negative consequences occur, destroying the natural composition of the soil and altering the top and bottom layers, resulting in the suppression of the soil fauna, disruption of the structure and water stability of aggregates, and an increase in the number of macro-aggregates (Baybekov, 2018). Plowed soil dries out faster, subject to erosion, decreasing the organic matter content. With combined deep, combined minimal, zero tillage systems, the valuable structural aggregate content (0.25–10 mm) increases compared with moldboard plowing, and the proportion of the blocky fraction (macroaggregates greater than 10 mm) decreases. In addition, with direct sowing, agronomically valuable aggregates' formation is in optimal quantities, with higher water stability observed in the soil; but, with traditional cultivation technology, the proportion of the dust fraction increases, enhancing the soil's susceptibility to erosion and deflation (Volters *et al*., 2020).

Table 3. Soil density with the crops under study in spring and summer (0–30 cm layer - g/cm^3).

Culture	Processing methods	In spring		Average	Qualitative assessment	In summer		Average	Qualitative assessment
		2021	2022			2021	2022		
Spring barley	Plowing	1.17	1.18	1.18	Loose	1.28	1.30	1.29	Medium compacted
	Minimal processing	1.19	1.20	1.20	Loose	1.29	1.32	1.31	Medium compacted
	No-till	1.22	1.22	1.22	Poorly compacted	1.31	1.33	1.32	Heavily compacted
Peas	Plowing	1.16	1.18	1.17	Loose	1.27	1.30	1.29	Medium compacted
	Minimal processing	1.18	1.20	1.19	Loose	1.29	1.32	1.31	Medium compacted
	No-till	1.21	1.21	1.21	Poorly compacted	1.31	1.33	1.32	Heavily compacted
Safflower	Plowing	1.18	1.17	1.18	Loose	1.27	1.28	1.28	Medium compacted
	Minimal processing	1.19	1.19	1.19	Loose	1.29	1.30	1.30	Medium compacted
	No-till	1.21	1.21	1.21	Poorly compacted	1.31	1.31	1.31	Heavily compacted
Sudan grass	Plowing	1.17	1.16	1.17	Loose	1.28	1.29	1.29	Medium compacted
	Minimal processing	1.20	1.18	1.19	Poorly compacted	1.3	1.31	1.31	Medium compacted
	No-till	1.22	1.20	1.21	Poorly compacted	1.32	1.32	1.32	Heavily compacted

Table 4. Agronomically valuable and water-resistant aggregates under crops of spring barley, peas, safflower, and Sudan grass with different soil cultivation methods (%).

Culture	Soil treatment methods	Agronomically valuable aggregates			Qualitative assessment	Waterproof units			Qualitative assessment
		2021	2022	average		2021	2022	average	
Spring barley	Plowing	63	61	62	Excellent	13.8	15.9	14.9	Unsatisfactory
	Minimal processing	65	64	65	Excellent	17.0	18.5	17.8	Unsatisfactory
	No-till	68	69	69	Excellent	21.2	21.8	21.5	Not satisfactory enough
Peas	Plowing	62	58	60	Excellent	16.1	12.5	14.3	Unsatisfactory
	Minimal processing	66	62	64	Excellent	19.1	14.3	16.7	Unsatisfactory
	No-till	72	64	68	Excellent	21.8	15.9	18.9	Not satisfactory enough
Safflower	Plowing	56	60	58	Good	15.6	13.6	14.6	Unsatisfactory
	Minimal processing	69	62	66	Excellent	19.7	14.4	17.1	Unsatisfactory
	No-till	77	65	71	Excellent	20.1	16.8	18.5	Not satisfactory enough
Sudan grass	Plowing	58	63	61	Good	14.4	11.8	13.1	Unsatisfactory
	Minimal processing	67	65	66	Excellent	18.5	12.7	15.6	Unsatisfactory
	No-till	70	68	69	Excellent	20.6	14.6	17.6	Unsatisfactory

Table 5. Grain yield of spring barley, peas, safflower, and Sudan grass based on soil cultivation methods (t/ha).

Culture	Plowing			Minimal processing			No-tillNo-till		
	2021	2022	average	2021	2022	average	2021	2022	average
Spring barley	1.23	2.69	1.96	1.55	3.29	2.42	1.06	2.98	2.02
Peas	0.90	1.01	0.96	0.88	1.44	1.16	0.96	0.79	0.88
Safflower	0.85	0.90	0.88	0.76	1.09	0.93	0.65	0.85	0.75
Sudan grass	0.70	0.63	0.67	0.74	0.87	0.81	0.84	0.93	0.89

$LSD_{0.05}$ 2021 = 1.159, $LSD_{0.05}$ 2022 = 2.402.

In our experience, an assessment of the structural and aggregate composition of the arable soil layer (0–30 cm) showed that the content of agronomically valuable aggregates (10–0.25 mm) has soil cultivation methods influencing it to a greater extent, compared with crops (Table 4). The soil cultivation methods ensured excellent structural conditions during the growing season of the studied crops (58%–71%) of agronomically valuable aggregates (0.25–10 mm) during dry sifting. The maximum content of structural aggregates was distinct in safflower, spring barley, and Sudan grass with zero tillage (69%–71%). It indicates the excellent aggregate state of the soil in natural conditions with these crops. The minimum amount of the structural aggregates was evident with sowing safflower and plowing at 20–22 cm (58%). The content of water-resistant aggregates was the highest in the no-tillage variants of the crops under study, with the indicators varying between 17.6%–18.9%. With plowing at 20–22 cm, the water resistance of aggregates in crops declined to 13.1%. The water-resistant aggregate content (13.1%–21.5%) indicated unsatisfactory formation of water stability and insufficiently stable soil composition in structure, respectively. The results further signified the urgent need to improve the constitution of the studied soils to enhance the content of water-resistant aggregates by introducing organic fertilizers and increased grass sowing, mainly alfalfa and green manure crops.

Thus, the crops and soil cultivation methods occupy a leading position in the structural conditions of the soil. It was also apparent in past studies that the frequent loosening of the soil contributes to destroying soil's aggregative state, with its upper layer dispersed and a blocky fraction formed (Zhapayev *et al*., 2023c; Denisov *et al*., 2006). Refusal to loosen the ground approaches the influence of the natural plant community and the soil fertility and agrophysical indicators. The use of zero tillage for more than 10 years optimizes the soil fertility and leads to boost the valuable agronomic aggregates.

Crop productivity

Losses due to unfavorable conditions in some crop seasons may be up to 50%–65% (Kovtunova *et al*., 2022). The crops' productivity largely depends on precipitation, especially during the growing season of the plants. In this regard, for the reasonable use of rainfed lands in Southeast Kazakhstan, switching to soil protection technology using drought-resistant crops is necessary (Beisenbayeva *et al*., 2021; Kenenbayev *et al*., 2022; Turebayeva *et al*., 2021; Kireev and Saparov, 2010; Zhapayev *et al*., 2023d). Long-term flat-cut tillage in crop rotation helps in conserving the organic matter (2.68%) compared with moldboard tillage (2.23%) and has a considerable positive impact on the biological activities of the soil (Dneprovskaya and Pilipenko, 2005; Loshakov, 2018).

The presented studies showed that the assessed crops' productivity was at 0.63–3.29 t/ha (Table 5). On average, over two years, the highest yield was distinct with minimal tillage in spring barley (2.42 t/ha), whereas the lowest grain yield occurred with plowing in Sudan grass (0.67 t/ha); however, with minimal and no-tillage the Sudan grass yields enhanced to 0.81 and 0.89 t/ha, respectively. As a result of a two-year study, it was confirmatory that the highest grain yields surfaced with minimal tillage in spring barley, peas, and safflower, and Sudan grass with no tillage. One must note that, in this area, the no-tillage option has been in application since 2018, and there was a slight increase in crop yields with minimal and zero tillage methods. Zhang *et al*. (2015) and Keil *et al*. (2020) reported that zero tillage stabilizes crop yields over the years, and to realize the potential, it takes at least four to six years (He et al., 2011). Additionally, in the first years, with zero tillage, the grain yield incurred significant decreases compared with plowing; however, by the sixth and seventh, the difference gradually reduced, and by the ninth year, notable advantages emerged (Polyakov, 2021).

Data processing by two-factor analysis of variance showed significant effects of the studied crops, tillage methods, and their interaction (Figure 2). However, the share of crops' contribution to the formation of grain yield was dependent on the years of research, ranging from 73.6%–93.8%, while the fraction of soil cultivation methods was 2.15%–2.89%, and the share of an interaction of both factors was 2.39%–18.4%. Notably, grain yield formation was largely reliant on the studied crops, with the dependence only increasing in association with weather conditions during the growing season of the crops.

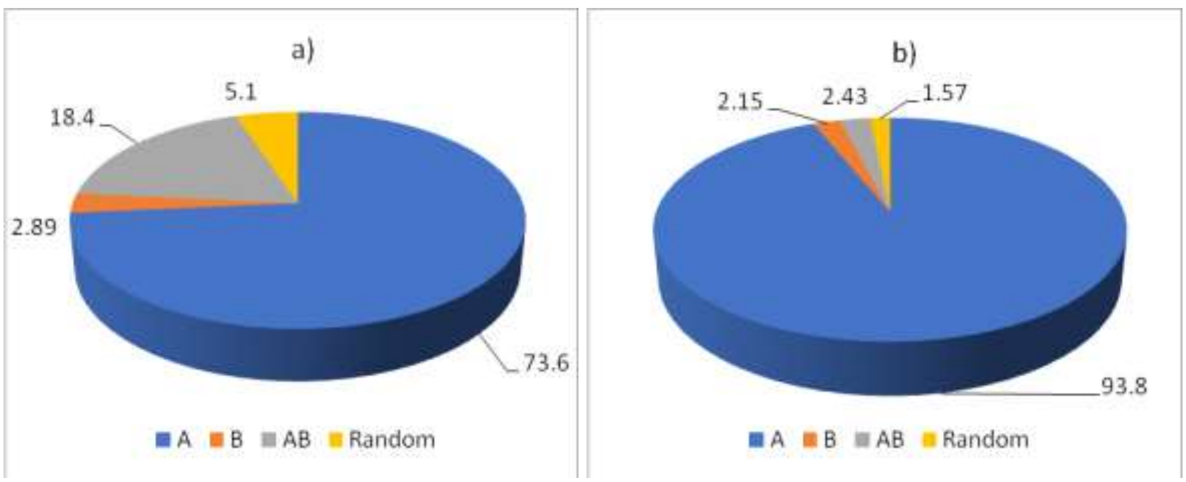

Figure 2. Two-way ANOVA of four crops: (a) 2021, (b) 2022, where A: Crops, B: Soil cultivation method, AB: Crops and Soil cultivation methods.

CONCLUSIONS

In rainfed conditions of Southeast Kazakhstan, the highest grain yields of the studied crops were verifiable with minimal tillage (8–10 cm), and during the beginning of harvesting, the productive moisture reserve was higher than plowing at 20–22 cm. Using zero tillage contributed to the formation of an excellent state of aggregation of the arable layer soil in the growing season of the studied crops (69%–71%), and the water-resistant aggregate content was also maximum in the variants of zero tillage under study, varying within 17.6%–18.9%, which indicates unsatisfactory water stability of the soil structure. Based on the two-way analysis of variance, the crop cultivars' contribution toward grain yield formation of the studied crops depended on the crop season at 73.6%–93.8%, while the share of soil cultivation methods was 2.15%–2.89%. Thus, grain yield formation mainly relied on the assessed crops, and the dependence only increased over crop seasons in association with weather conditions during the crops' growing season.

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