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PRIMARY TILLAGE IMPACT ON SPRING BARLEY (*HORDEUM VULGARE* L.) YIELD UNDER SEMIARID RAINFED CONDITIONS OF SOUTHEAST KAZAKHSTAN

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SUMMARY

The presented research aimed to study primary tillage impact on spring barley (*Hordeum vulgare* L.) yield, carried out on light chestnut soils under semiarid rainfed conditions in the foothill zone of Trans-Ili Alatau, Kazakhstan. The barley field experiments comprised three tillage methods, viz., traditional, minimum, and zero-tillage. The minimum and zero-tillage tillages clearly emerged with increased plant biomass (11.15 and 8.87 t/ha, respectively) compared with traditional plowing (7.62 t/ha); they also enhanced the 1000-kernel weight (32.2 and 31.9 g) versus 28.0 g for traditional, respectively. During the growing season, the agrochemical analysis revealed the decline of nitrate nitrogen contents in all variants from 26–25 to 17–15 mg/kg, which may be due to its intensive use by plants. Moreover, the available phosphorus and exchangeable potassium were characteristically higher values than the minimum and no tillage (364–357 mg/kg), whereas with the traditional plowing, this figure was 302 mg/kg, enunciating a more efficient use of nutrients under resource-saving technologies. A comparative assessment of grain yield showed the highest productivity was successful with minimum tillage (2.53 t/ha), which exceeds the traditional plowing (2.07 t/ha) by 0.46 t/ha and no tillage (1.85 t/ha) by 0.68 t/ha. However, the no-tillage was evidently with greater variability in the grain yield in crop seasons.

Keywords: Spring barley (*H. vulgare* L.), climate change, minimum and zero-tillage, dry farming, soil moisture, soil bulk density, plant biomass, grain yield, yield components

Key findings: Under moisture deficit conditions, minimum tillage was recognizably the most effective approach, ensuring an optimum grain yield and rational use of resources in the spring barley (*H. vulgare* L.). No-till is a promising resource-saving technology, and traditional plowing is inferior for key agronomic indicators.

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the world's oldest and most adaptable cereal grains, grown well in cooler and temperate climates, ranking as the fourth most produced crop globally. It thrives in diverse climates, including drought-prone regions and high-altitude areas. Barley is also crucial to global agriculture for its role in animal feed, human nutrition, and the malting industry. In 2023, barley was fourth among grains in quantity produced (146 million tons), behind maize, rice, and wheat. Globally, 70% of barley production usage served as animal feed, while 30% was a source of fermentable material (FAOSTAT, 2023). In 2025, the area under spring barley cultivation in Kazakhstan was approximately 2.3 million hectares, including over 422,000 hectares in the south and southeast of Kazakhstan. Moreover, the gross harvest was approximately 3.6 million tons, including over 108,000 tons in the south and southeast of Kazakhstan (KAZSTAT, 2025).

` In improving the sustainability and productivity of arable lands of Southeastern Kazakhstan, as well as to improve their ecological conditions and rational use of climatic and soil resources, it is necessary to develop the soil-protective and resource-saving technology. This will considerably preserve and increase the soil organic matter and reduce carbon emissions. Previous research conducted on rainfed lands of Southeastern Kazakhstan had made general conclusions. The zero-tillage technology on gray soils with light mechanical composition and poor rainfed lands has an undeniable advantage over mechanical and traditional methods of soil cultivation. Likewise, on light chestnut soils with heavier mechanical composition, the direct seeding was a possible subject to the intensification of grain crop cultivation technology (Kireev, 2010).

In modern agriculture, one of the main tasks is to preserve and improve the soil fertility, as well as to considerably enhance the productivity of crop cultivation (Valkama *et al.*, 2020). Soil fertility management involves regulating soil processes by using various tillage methods, which may develop optimal conditions for better plant growth. Furthermore, the cultivation of different crops also consumes mineral and organic matter, deteriorates soil, water, and air conditions, and affects phytosanitary conditions. The tillage remains the most important measure in the agricultural system, determining the water, air, and mineral nutrition of crop plants while significantly influencing the yield in field crops (Kuzina and Yakunin, 2016).

Modern agriculture considerably faces pressing challenges of reducing the adverse impact of tillage on soil fertility. Therefore, it is essential to use the land rationally and improve the soil fertility to achieve high and sustainable crop yields and the highest possible output per unit area with minimal labor and financial inputs. A key approach to addressing these issues could be the use of minimum tillage and zero tillage, which are more cost-effective than costly traditional plowing. In previous years, several past studies demonstrated the possibility of restoring and preserving the fertility of arable soils by switching from a traditional farming system with moldboard cultivation to soil conservation technology (Zhapayev *et al.*, 2023a).

The most promising soil conservation technologies include minimum and no-tillage or direct seeding, which have reached a worldwide practice on an area of 205 million hectares (Mrabet *et al.*, 2022). Additionally, no-tillage helps reduce soil erosion and dehumification, improves soil physical properties, increases biological activity and fertility, and eventually improves the ecological state of the soil (Mrabet *et al.*, 2022), as well as saving field resources and increasing the profitability of agriculture (Rosner *et al.*, 2008). Thus, the aim of this research was to evaluate the impact of different methods of primary tillage on moisture availability, agrochemical properties of the soil, and the yield of spring barley to identify the most effective resource-saving technology.

MATERIALS AND METHODS

Plant material and experimental design

The following research concerning the impact of tillage methods on the hydrophysical and agrochemical properties of soil commenced in 2021–2023 at the Kazakh Research Institute of Agriculture and Plant Growing, Almaty, Kazakhstan. The establishment of field experiments on spring barley (*H. vulgare* L.) comprised three tillage methods (traditional, minimum, and no-till) on light chestnut soils, located in the foothill zone of the Trans-Ili Alatau, Kazakhstan (Figure 1). The soil has an average supply of easily hydrolyzable nitrogen, low available phosphorus, and average exchangeable potassium. The upper horizon contains humus (2.02%) and total nitrogen (0.12%–0.14%). The laboratory studies and soil analysis continued at the Soil Science and Agrochemistry Laboratory, Kazakh Research Institute of Agriculture and Plant Growing. The field experiment, observations, and data recording proceeded according to the methodology of Dospekhov (1985). The determination of water-physical properties of the soil transpired following the methodology of Kachinsky (1970). The nitrate determination used the TSINAO method GOST26488-85, while the mobile phosphorus and potassium in carbonate soils were determined and used the Machigin method, as modified by TSINAO and GOST26205-91.

Meteorological conditions

The spring of 2021 was reportedly wetter (88.9 mm) and warmer than long-term averages, particularly in March, which was 3.4 °C above long-term averages (Table 1). Precipitation in March contributed to sufficient soil moisture accumulation for uniform emergence of the spring barley crop. All summer months, except August, were 1.9 °C–2.7 °C hotter than the long-term average, with precipitation falling 30.8 mm below the normal. Agrometeorologically, the summer was characteristically extremely dry and hot. All these environmental factors considerably affect plant growth and development, and ultimately, the grain yield in barley.

According to meteorological data, the spring of 2022 was wetter (by 193.9 mm) and warmer than long-term averages. Precipitation in March and April contributed to sufficient soil moisture accumulation for uniform emergence of the spring barley crop. Significant precipitation in May also provided additional accumulation of productive soil moisture and

Figure 1. Spring barley in the germination and heading phases with no tillage in the foothill zone of the Trans-Ili Alatau, Kazakhstan.

Table 1. Meteorological conditions for the spring barley growing season 2021–2023 (obtained from Almalybak weather station).

Month	Every 10 days	Atmospheric precipitation (mm)				Air temperature (°C)			
		2021	2022	2023	Medium-long-term	2021	2022	2023	Medium-long-term
March	I	25.9	31.1	20.7	13.7	5.3	6.9	8.9	3.7
	II	33.9	66.6	38.8	26.1	-1.6	5.1	6.1	2.3
	III	58.1	70.9	1.7	25.8	8.5	5.4	10.3	7.2
	In a month	117.9	168.6	61.2	65.6	4.1	5.8	8.4	4.4
April	I	32.1	6.5	14.0	30.7	8.3	17.2	9.9	8.4
	II	4.0	5.3	50.3	35.7	15.7	17.5	10.9	11.9
	III	20.2	35.0	3.9	42.1	13.3	15.4	14.9	14.1
	In a month	56.3	46.8	68.2	108.5	12.4	16.7	11.9	11.5
May	I	64.9	13.7	4.2	29.6	18.8	20.5	13.0	15.0
	II	15.8	61.3	10.8	24.1	16.6	18.5	20.4	16.9
	III	0.9	70.4	28.4	25.4	22.7	17.9	18.2	18.6
	In a month	81.6	145.4	43.4	79.1	19.4	19	17.2	16.8
June	I	7.1	4.8	-	25.7	25.7	22.4	25.5	20.4
	II	2.6	6.2	1.1	18.7	21.3	23.9	24.9	21.5
	III	11.2	24.9	3.2	14.0	22.3	26.7	23.5	22.3
	In a month	20.9	35.9	4.3	58.4	23.1	24.3	24.6	21.4
July	I	1.4	6.2	14.9	18.4	29.7	24.9	23.7	23.7
	II	21.4	0.6	-	72.2	23.3	25.7	29.4	24.0
	III	-	8.3	18.7	14.1	27.6	28.9	28.2	23.9
	In a month	22.8	15.1	33.6	104.7	26.9	26.5	27.1	23.9
Head of vegetation		299.5	411.8	210.7	416.3	17.2	18.5	17.8	15.6

further growth and development of spring barley plants. All the summer months, except August, were 2.4 °C–3.1 °C hotter than the long-term average, and precipitation was 56.7 mm below normal. According to agrometeorological conditions, the summer period had extremely dry and hot features. However, precipitation in the spring period contributed to the accumulation of a sufficient supply of moisture in the soil, which ultimately affected the grain yield in barley crops.

Overall, the weather conditions in 2023 were unfavorable for the growth and development of the studied drought-resistant crop due to moisture deficit conditions and hot summer weather. Precipitation in January and February totaled 70.9 mm, 12.4 mm below the long-term average, while in spring, it totaled 172.8 mm, 80.4 mm below the long-term average. A moisture deficit was also evident in the summer, resulting in precipitation of 110.8 mm, 87.3 mm below the long-term average. Of this, 72.9 mm precipitation fell only in August, i.e., during grain formation for the studied crop. Hot weather with little precipitation transpired in June and July in 2023.

Agricultural technology of spring barley

Field experiments to study various soil cultivation methods in spring barley took place under rainfed conditions in Southeastern Kazakhstan. Under semiarid rainfed conditions of Southeastern Kazakhstan, the spring barley cultivar Symbat was the variety used, along with soil cultivation methods (plowing to a depth of 20–22 cm, minimum tillage at 8–10 cm, and no-till). The field experiments conducted were in triplicate, with plots systematically placed. The barley seeds entailed sowing in the third 10-day period of March using a VenceTudo-7500 direct seeding drill (Brazil), with 100 kg of ammophos applied to the rows. After sowing, the minimum- and no-till systems received treatments with a glyphosate-containing herbicide at the rate of 3 l/ha against all types of weeds. During the tillering phase of spring barley, the crops incurred treatment with Efir Premium herbicide at the rate of 0.5 l/ha in a tank mix with the Beres Amino Max growth stimulant at the rate of 0.5 l/ha. In the spring, during the 3–4 leaf stage, the crops obtained fertilization with ammonium nitrate at the rate of 100 kg per hectare.

RESULTS AND DISCUSSION

Water-physical properties of soil

Kazakhstan, as characterized by uneven rainfall and high evaporation, had this problem most acute in the southern and southeastern regions. Spring barley (*H. vulgare* L.) is one of the most drought-resistant grain crops due to its short growing season, high plasticity and adaptability, and ability to effectively utilize limited soil moisture reserves (Ceccarelli *et al.,* 2010). The conservation and efficient use of productive soil moisture during the growing season has been recognizably one of the main factors influencing the productivity of spring barley. One should also note that in arid zones, the best results emerged by cultivating crops using the no-till technology (Gadzhiumarov *et al.,* 2022). On the soil surface, the mulching layer of plant residues preserves the moisture from evaporation and improves its infiltration to make it available to plants during dry periods (Mrabet, 2011).

The potential research revealed the highest productive moisture contents in the one-meter soil layer appeared during the initial period of vegetation, with a subsequent decrease toward the end of the growing season. In spring barley, with traditional plowing to a depth of 20–22 cm, the following values resulted: 115.4 mm at the emergence stage, 78 mm during the grain-filling stage, and 20.8 mm before harvesting (Table 2). These values were the lowest among the studied tillage methods, which may indicate less effective conservation of moisture and soil structure. With minimum tillage to a depth of 8–10 cm, the highest values were notable in the early and middle stages of spring barley plants' development, compared with traditional plowing, with an increase of 12.5, 4.9, and 2.1 mm, respectively. This revealed a positive effect of minimum tillage on the plant growth and development in spring barley. Under no-tillage conditions, the values also exceeded those obtained with traditional plowing, with the maximum value of 25.5 mm noted at the end of the growing season (before harvesting) among all the options. This was 4.7 mm higher than with plowing and 2.6 mm higher than with minimum tillage. Thus, the results enunciated that minimum and no-tillage methods provided superior growth performance for spring barley compared with traditional plowing. According to previous studies, conservation tillage systems considerably improved the soil structure and water retention, which positively affects the crop's development throughout the growing season (Hobbs *et al.,* 2008; Farooq *et al.,* 2011).

Soil bulk density is an indicator of the agrophysical condition of the arable soil, which considerably affects plant growth and development, as well as crop productivity. Therefore, the soil bulk density should be within an optimal range. For most crops, the optimal soil bulk density range in loamy soils tended to be 1.00–1.30 g/cm^3 (Kurchenko *et al.,* 2018). However, as the total humus content decreases, the optimal soil bulk density shifts toward compaction. Soil bulk density primarily depends on the tillage

Table 2. Dynamics of productive moisture reserves (mm) depending on soil cultivation methods in spring barley (average for 2021–2023).

Variants	Deadlines for determination		
	Germination phase	Grain pouring	Before cleaning
Plowing to a depth of 20–22 cm	115.4	78.0	20.8
Minimum 8–10 cm	127.9	82.9	22.9
No-till	125.2	81.8	25.5

Table 3. Dynamics of soil density (g/cm^3) depending on soil cultivation methods in spring barley (average for 2021–2023).

Variants	Germination phase	Qualitative assessment	Before harvesting crops	Qualitative assessment
Plowing to a depth of 20–22 cm	1.17	Loose	1.29	Medium compacted
Minimum 8–10 cm	1.19	Loose	1.30	Very compacted
No-till	1.21	Poorly compacted	1.32	Very compacted

methods, as actively discussed in various studies, including no-tillage, in which the prolonged cessation of primary tillage promotes the formation of plant mulch, serving as a litter substitute for plant litter (Polyakov, 2021).

During the emergence phase, with conventional plowing to a depth of 20–22 cm, the soil bulk density was 1.17 g/cm³, characterized as a loose structure (Table 3). With minimum tillage (8–10 cm), this indicator was slightly higher (1.19 g/cm³) but still corresponds to a loose soil condition. However, during this period, the highest value of the soil bulk density was evident with no-tillage (1.21 g/cm³), with the soil assessed as slightly compact. Before harvesting spring barley, an increase in soil bulk density emerged across all tillage methods. Under traditional plowing, the soil bulk density reached 1.29 g/cm³, corresponding to a moderate degree of compaction. Under minimum tillage conditions, the soil bulk density increased to 1.30 g/cm³, indicating highly compact soil. However, the highest soil bulk density recorded was with no-tillage conditions (1.32 g/cm³), which also demonstrated severe soil compaction. These results were greatly analogous to previous studies showing that reduced and no-tillage systems tend to increase the soil bulk density, especially in the upper soil layers, due to no mechanical loosening (Hamza and Anderson, 2005).

Agrochemical properties of soil

Tillage improves soil conditions for optimal seedling emergence and grain yield (Khorami *et al.,* 2018). Initially, traditional tillage improved the physical and chemical properties of the soil (Busari *et al.,* 2015). However, over time, due to the deterioration of the soil structure, farmers now switched from traditional tillage to zero tillage, which has greater potential for sustainable crop production without environmental pollution (Li *et al.,* 2020). Traditional tillage mostly involves deep plowing and disc harrowing, which severely disrupts the soil's physical and agrochemical properties. Meanwhile, zero tillage with less soil disturbance enhanced the stubble accumulation, which enriches the arable soil with nutrients and organic matter (Veiga *et al.,* 2008). The nitrate nitrogen content significantly varied from year to year, and the addition of 70 kg ha^{-1} active substance of ammonium nitrate to the fertilizer considerably boosted the content of nitrate nitrogen. Consequently, the higher the soil's supply with it, the less influence fertilizers have on this indicator (Gajda *et al.,* 2018).

Similar studies of light chestnut soils have shown that said soils, with the timely use of minimum tillage methods and cover crops, revealed the potential to preserve organic matter. Likewise, these improve agrochemical properties by minimizing degradation of the upper humus horizon. This was especially important for sustainable agriculture models, where the soil carbon conservation has a direct link to soil structure, stability, and water-holding capacity (Valkama *et al.,* 2020; Kunypiyaeva *et al.,* 2023; Zhapayev *et al.,* 2023a, 2023b, 2023c).

The nitrate nitrogen content at the plant's emergence phase was virtually identical across all the variants, amounting to 26 mg/kg with traditional plowing and minimum tillage and 25 mg/kg with no tillage (Table 4). However, at the time of harvesting, a considerable decrease occurred in nitrate nitrogen content for all experimental variants, i.e., 17 mg/kg with traditional plowing, 16 mg/kg with minimum tillage, and 15 mg/kg

Table 4. Dynamics of the content of mobile nutrients (mg/kg) depending on soil cultivation methods in spring barley (average for 2021–2023).

Variants	Nitrate nitrogen		Mobile phosphorus		Exchangeable potassium	
	Germination phase	Before cleaning	Germination phase	Before cleaning	Germination phase	Before cleaning
Plowing to a depth of 20–22 cm	26	17	41	22	367	302
Minimum 8–10 cm	26	16	39	31	400	364
No-till	25	15	34	26	407	357

with no tillage. The results revealed that the active nitrogen uptake by plants during the growing season, which was consistent with previous studies, reported a decline in soil nitrate levels due to crop uptake and transformation processes (Havlin *et al*., 2014). Available phosphorus levels at the plant's emergence stage were highest with traditional plowing (41 mg/kg), slightly lower with minimum tillage (39 mg/kg), and lower with no tillage (34 mg/kg). However, before harvesting, the divergent dynamics were observed: with plowing, phosphorus levels decreased to 22 mg/kg; with minimum tillage, the phosphorus levels increased to 31 mg/kg; and with no tillage, it reached 26 mg/kg. This may indicate the differences in phosphorus transformation and availability based on the soil cultivation methods. Minimal and no-till practices have limited the phosphorus availability due to biological activity and soil mixing (Sharpley, 2003).

On the exchangeable potassium content at the germination phase, the lowest value was remarkable with traditional plowing (367 mg/kg), while in minimum tillage and zero tillage, the figures were higher (400 and 407 mg/kg, respectively). By the time of harvest, the potassium content decreased in all variants: 302 mg/kg with traditional plowing and 364 and 357 mg/kg with minimum and zero tillage, respectively, which may refer to the removal of the element by the crop. Higher concentrations of copper (Cu) were apparent under minimum tillage (1.41 mg kg^{-1}) than under no tillage (1.10 mg kg^{-1}). However, conservation tillage did not consistently increase the total P and K, with improvements limited to the 0–10 cm soil layer (Calistru *et al.,* 2024).

Spring barley structural elements of harvest and grain yield

In spring barley structure, the key indicators were plant height, biomass formation, and 1000-grain weight. The present results revealed that with traditional plowing and no tillage, the plant height was 75 cm, while with minimum tillage, the plant height was 76 cm, indicating a nonsignificant effect of soil cultivation methods on this trait (Table 5). However, significant differences resulted in terms of plant biomass. The lowest value of plant biomass appeared with traditional plowing (7.62 t/ha). With minimum tillage, the biomass significantly increased to 11.15 t/ha, which is 3.53 t/ha higher than the traditional plowing. With no tillage, the plant biomass was 8.87 t/ha, which also exceeds traditional plowing by 1.25 t/ha but was inferior to minimum tillage. A similar trend emerged for 1000-grain weight. With traditional plowing, the 1000-grain weight was 28.0 g, while with minimum tillage, it increased to 32.2 g, with a rise of 4.2 g. With no tillage, it was up to 31.9 g, with an increase of 3.9 g compared with traditional plowing. No-tillage technologies can provide biomass accumulation and raise soil particle mass through stable soil structure and moisture retention (Derpsch *et al.,* 2010).

In spring barley, on average, the grain yield over three years of research was in the range of 1.85–2.53 t/ha, depending on the methods of soil cultivation (Table 6, Figure 2). With conventional plowing, grain yields were 1.23 t/ha in 2021, 2.69 t/ha in 2022, and 2.29 t/ha in 2023, with an average of 2.07 t/ha. Significant variation was noticeable among the crop seasons, which may be ascribable to weather conditions. With minimum tillage, the

Table 5. Elements of plant productivity of spring barley depending on soil cultivation methods.

Variants	Plant height (cm)	Plant biomass (t/ha)	1000 grain weight (g)
Plowing to a depth of 20–22 cm	75	7.62	28.0
Minimum 8–10 cm	76	11.15	32.2
No-till	75	8.87	31.9

Table 6. Grain yield of the spring barley depending on soil cultivation methods.

Variants	Yield (t/ha)			Average
	2021	2022	2023	
Plowing to a depth of 20–22 cm	1.23	2.69	2.29	2.07
Minimum 8–10 cm	1.55	3.29	2.76	2.53
No-till	1.08	2.98	1.49	1.85
$LSD_{0.05}$	0.151	0.149	0.115	

Figure 2. Spring barley crop in the phase of full grain maturity and grain yield assessment.

highest grain yields were 1.55 t/ha in 2021, 3.29 t/ha in 2022, and 2.76 t/ha in 2023, with an average of 2.53 t/ha. Compared with traditional plowing, the grain yield increases averaged 0.46 t/ha, demonstrating the high efficiency of minimum tillage. With no till, the grain yields were 1.08 t/ha in 2021, 2.98 t/ha (2022), and 1.49 t/ha (2023), with an average of 1.85 t/ha. Despite the relatively high yield in 2022, this option was generally inferior to both minimum tillage and traditional plowing, yielding 0.22 t/ha, on average. Minimum tillage often results in higher and more stable yields in water-scarce environments, while yield fluctuations between crop seasons were largely under climatic factors' control (Kassam *et al.,* 2009).

CONCLUSIONS

The results revealed soil cultivation methods significantly affect the conditions for spring barley (*H. vulgare* L.) crop formation. The minimum and no-tillage techniques contribute to better conservation of soil moisture, which gave reflections in an increase in plant biomass with minimum tillage (11.15 t/ha) and no tillage (8.87 t/ha) versus traditional plowing (7.62 t/ha). Minimum and no tillage also enhanced the 1000-grain weight (32.2 and 31.9 g, respectively) compared with the conventional plowing (28.0 g). The highest yields were reachable with minimum tillage (2.53 t/ha), exceeding traditional plowing (2.07 t/ha) by 0.46 t/ha and zero tillage (1.85

t/ha) by 0.68 t/ha. Zero tillage showed characteristics of greater yield variability across crop seasons.

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