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RESEARCH ARTICLE
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Optimizing Tillage Systems and Cultivation Practices for Enhancing Productivity of Dark Chestnut Soils in Northwestern Kazakhstan

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ABSTRACT

Significant land areas in Kazakhstan have been taken out of agricultural use, leading to large tracts of fallow land. If left unmanaged, these lands can become infested with weeds, deteriorating the phytosanitary condition of the region. Fallow lands also play a role in restoring soil fertility and represent a reserve for agricultural use. The study aimed to analyze the influence of tillage methods and cultivation technologies on the productivity of dark chestnut fallow soils in northwestern Kazakhstan. Field experiments were conducted from 2018 to 2022 on dark chestnut-heavy loam soils. The study included the analysis of soil properties, including moisture content, density, nutrient availability, and biological activity. The effectiveness of soil tillage methods was assessed through the cultivation of spring wheat and perennial grasses, using a three-factor experimental design with three replications. The primary tillage methods compared were deep plowing, chisel plowing, and shallow loosening. After 8 years, observations showed that, fallow soils become close to virgin soil. However, their water regime becomes unfavorable. Deep moldboard and boardless tillage on black fallow soil served as most appropriate agricultural and technological practices to improve water regime, soil compaction, crop yield, and soil structure in this arid region.

Keywords: Agricultural use; Weeds; Soil fertility; Soil cultivation; Virgin soil

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INTRODUCTION

Significant areas of land in Kazakhstan have been withdrawn from agricultural production and transferred to the fallow land category (Popov et al., 2017). Large areas of land cease to be developed and sown with grain and forage crops and, as a result of their irrational use, turn into wasteland (Zhyrgalova et al., 2024). The development of fallow lands in these regions is necessary to increase food production and security (Zharkov et al., 2023). The initial stages of fallow land restoration are characterized by the development of weedy vegetation unsuitable for economic use and having an unfavorable phytosanitary condition (Kucherov et al., 2013). With the aging of the fallow land, the process of replacing weed vegetation with steppe vegetation begins due to a change in soil properties. In the fallow soils, with the passage of soil-forming processes, the profile gradually differentiates, the surface turf horizon develops, dense composition and structure are formed and organic matter accumulates (Kurishbayev et al., 2016). In many grain-producing countries, soil fertility programs are implemented, as it periodically becomes necessary to turn arable land into fallow land due to the deterioration of its properties (Toth et al., 2016). Fallow land farming programs and methods restore soil properties and regulate the balance of food resources (Ferng, 2009; Lu et al., 2019). Recent studies reported, the possibilities of improving the productivity of fallow lands by using them as black fallow with legumes (Kumar et al., 2019; Mamuye et al., 2020).

Environmental problems of wasteland and fallow lands that pose a threat to the spread of harmful organisms have been studied by many scientists (Boincean et al., 2019; Moreira et al., 2024). These researchers also described the basics of subsidizing fallow lands. From an economic point of view, fallow land is unprofitable. Being reserves of harmful organisms, wastelands cause a steady risk of a constant threat of the spread of malicious weeds and invasions of pests and pathogens on crops. At the first

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stages of re-establishing vegetational cover, fallow lands have weedy vegetation, which worsens the phytosanitary conditions of the region and is a threat to the development of cultivated crops. Therefore, the use of fallow lands is pressing issue. However, fallow lands also have a positive role and perform important ecosystem functions: carbon deposition, rehabilitation of soil fertility, and restoration of steppe floral biodiversity (Amangaliev et al., 2023). An effective way to involve unused lands in agricultural turnover is to expand the areas of crops genetically resistant to local abiotic stresses (Rau et al., 2023; Zafar et al., 2024). Studies of fallow soils in an arid steppe region have shown the effectiveness of deep tillage in increasing crop rotation productivity (Bishop et al., 2024). Mechanical tillage is the most common type of soil tillage in agriculture. It is hardly possible to cultivate crops without it (Solodovnikov et al., 2021). Deep tillage is a promising agronomic practice to improve soil physicochemical properties and microbial diversity during the growing season and, ultimately, crop yields (Chen et al., 2024).

Moldboard plowing has been reported to increase moisture supply, decreased density, and increased availability of nutrients, such as nitrogen and potassium (Pakul et al., 2021; Popov, 2019). Reducing tillage depth leads to a decrease in the yield of feed and grain units. The lowest yield of forage and grain units was obtained in fields without basic tillage (Rzaeva, 2021). Deep plowing during the black fallow period contributes to the accumulation of natural precipitation and its movement into the depth of the soil horizon, contributing to an increase in wheat yield (Zhao et al., 2021; Li et al., 2022; Zhang et al., 2022). Wheat yield was higher during deep plowing and positively correlated with the water reserve in the soil with a thickness of 0-200cm during the wheat growth period (Dang et al., 2016). Many years of experience with the fallow lands conducted in Australia have shown the need for weed control in black fallow fields to ensure moisture accumulation for subsequent cultivation of winter crops (Zeleke et al., 2017). Fallow soil tillage is a common practice aimed at preserving soil moisture. However, without cover crops, the treated soil is exposed to erosive forces and reduced productivity. Fallow crop rotations improve moisture availability, microbial diversity, and soil fertility (Hux et al., 2023; Peralta et al., 2018; Xia et al., 2020). Tillage has a positive effect on wheat yield and soil fertility (Saison et al., 2006; Carrera et al., 2007). The development and cultivation of fallow lands is the most important reserve for increasing the production of grain, forage, and other crop production in Kazakhstan. Scientists, practitioners, and commodity producers are concerned with the issue of reclaiming land that has been withdrawn from circulation and the rational use of this land (Pismennaya et al., 2021).

Due to the prevailing economic difficulties in Kazakhstan, large areas of fallow lands have ceased to be used, and their return to economic circulation and development is currently causing difficulties due to the lack of effective agricultural techniques. The development of fallow lands should be carried out following scientifically sound soil tillage technologies. Thus, the objective of the study was to evaluate the effect of fallow land tillage methods on the agrophysical, agrochemical properties, and soil fertility of northwestern Kazakhstan.

MATERIALS & METHODS

Field experiments were conducted in the West Kazakhstan region at the Permsky LLP (Shalgai village (51°25′47″ N 50°44′41″ E) from 2018 to 2022. Climate in this region is sharply continental, dry, with hot summers and cold winters. Daily and annual temperature amplitude is very large. Spring and autumn are mildly cloudy insignificant. The average temperature in January is -19ºS, in some years reaches -51ºC in the summer ranges between +21 to +19ºC, to absolute maximum air temperature +43°C, the absolute minimum (-51)°C. The average annual precipitation is 300-350mm with average humidity around 70% (Committee of Highways of the Ministry of Transport of the Republic of Kazakhstan, 2016). The objectives of the study were dark chestnut heavy loamy soils in northwestern Kazakhstan: specifically comparing virgin land, old fallow land, and old arable land. During the years of the study, virgin and fallow lands with perennial vegetation were used as the control. The experiments were carried out with three-fold repetition in three sites independent concerning space and time (2018, 2019, 2020). Soil tillage systems and agricultural machinery of cultivated crops were used on the plowed fallow land. After plowing, the fallow land was used as black fallow. In the third year, wheat was sown in the fallow land. On the half of the plot with spring wheat, a mixture of alfalfa and wheatgrass was sown under the wheat cover. Sowing was carried out with SZP-3,6 seeders (fertilizer grain press seeders) followed by rolling.

Before the establishment of the experiments, the following observations were carried out: soil moisture was measured using the thermostat and weighing method using the AM-16 drill; soil density was determined using the N.A. Kachinsky drill; soil structure was analyzed using dry sieving according to the N.I. Savvinov method. The nitrate nitrogen content was determined by the Grandval and Lajous method, mobile phosphorus – by the Machigin method following State Standard (GOST) 26205-84, exchangeable potassium was extracted in a carbon-ammonium extract; the humus content was determined by the I.V. Tyurin method. The biological activity of the soil was studied by the rate of decomposition of linen fabric. To increase the reliability and objectivity of experimental data, the experiment design provided for the study of the productivity of two crop rotation links against the background of three main methods of fallow soil tillage. Weather conditions during the study were characterized by aridity, with a hydrothermal moisture coefficient from 0.29 to 0.41.

In each site, in the year of development of the fallow land, two-fold tillage with disk tools (Scan-Agro 300 disk harrow) was carried out for high-quality cutting of the sod cover. Then, against this background, three variants of basic tillage (factor A) were used in the fall: with a PN-4-35 plow (mounted four-furrow plow) at a depth of 25-27cm, with a KPG-250 blade cultivator (subsoil blade cultivator) to 25-27cm, and loosening (an element of minimizing tillage) with a PN-4-35 boardless plow at a depth of 14-16cm.

Subsequently, in these areas, the following crop rotation links were placed black fallow – spring wheat and black fallow – spring wheat + a cover grass mixture of alfalfa with wheatgrass – a grass mixture of the 2nd and 3rd year of life. To conduct experiments on accounting for the yield of spring wheat, the method of continuous combine harvesting was used for various variants and quickness (Fig. 1). To determine the yield of plant biomass on virgin land, fallow lands (control areas), and crops of perennial grasses, the method of parcels (sites) with an area of 20m2 (2 x 10m) was used in a three-fold repetition. The moisture content of the biomass was brought to the standard for hay (Piskunov, 2004). Biological and actual yield data were processed by the method of variance analysis in Microsoft Excel as presented by Gomez & Gomez (1984).

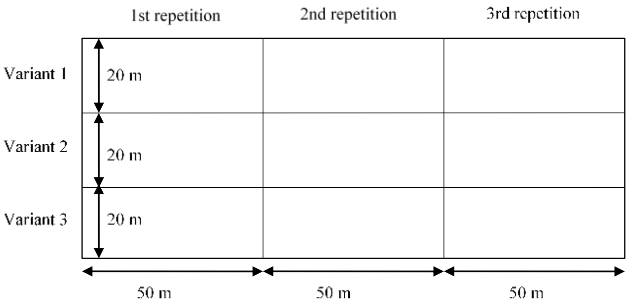

Fig. 1: Schematic layout of variants for basic soil tillage in field experiments (one site).

RESULTS

Effective development of fallow lands is possible using appropriate agricultural technology and crop selection. The effectiveness of soil tillage was determined by cultivating spring wheat and perennial grasses in the experiment. Research data show that fallow lands after 8 years become close to virgin land in terms of their agrophysical and agrochemical properties, i.e., they restore fertility (Table 1). The structure and biological activity in fallow soils increased by 1.5 times, and the content of total nitrogen and phosphorus increased by 30 and 15%. In fallow soils, with increasing time, the amount of humus also tends to increase, while the density decreases. However, in fallow soils, the water regime becomes extremely unfavorable, characterized by a decrease in the moisture absorption coefficient of precipitation. Due to the lack of available moisture in the soils, a dry layer is formed. After 8 years, fallow dark chestnut soils, compared with old arable soil, acquire more favorable agrochemical and agrophysical properties, and an appropriate water regime can ensure the realization of their potential fertility. The zones of chestnut soils are located in a sharply continental climate and, according to morphological characteristics, are characterized by a shortened humus horizon (A+B) and a lower humus content. The thickness of the A+AB horizon varies from 15 to 32cm. In the soils under arable land and fallow land (8 years), there are no significant differences in the distribution of humus. Sod was formed only on the surface of the soils under the fallow land. The distribution of humus by profile remained at the initial level (Table 2).

Table 1: Agrophysical and agrochemical properties of the studied soils (data for 2021)

Indicators of soil fertility	Horizon, soil layer	Arable land	Fallow land	Virgin land
Humus (humus-accumulative) horizon (cm)	A(Aar)+AB	23	26	32
Soil structure (coefficient)	A(Aar)	1.4	2.1	3.8
Soil density (g/cm^3)	A(Aar)	1.21	1.20	1.17
Soil density (g/cm^3)	AB	1.33	1.32	1.26
Total nitrogen (%)	A(Aar)	0.18	0.24	0.25
Mobile phosphorus (mg/100g)	A(Aar)	2.8	3.5	4.3
Exchangeable potassium (mg/100g)	A(Aar)	21.4	26.6	27.8
Biological activity (%)	0-20cm	21.4	32.1	41.4
Spring wetting depth (cm)	-	130-150	60-80	60-80
Available moisture reserves (mm)	wet	100-140	70-90	70-90
Thickness of the dry layer in spring (cm)	-	none	30-34	40-50

Table 2: Thickness of the humus horizon (cm) of the studied dark chestnut soils

Horizons	Arable land	Fallow land	Virgin land (average of two sections)
A0	-	2.3	1.8
A, Aar	15.0	16.0	16.0
AB	8.0	10.0	16.0
B	30.0	31.0	31.0
A (AP) + AB	23.0	26.0	32.0

The horizon profile (Aar + AB) in arable land is on average 23cm, in virgin land, it is 36cm, and in 7-year-old fallow lands, the humus horizon is 3cm (26cm) thicker in comparison with arable land. The low humus capacity of the AB horizon (typical for arable land) is due to the processes of its intensive use. This is confirmed by the quantitative determination of humus in soil samples taken from sections. In old arable and fallow soils on the upper horizon, the humus content was 2.7-2.9%, while in virgin soil it was 4.4% (Fig. 2). Virgin soils are characterized by a high content of valuable aggregates (78.7%) and a low content of lumpy particles (15.0%). The structural coefficient of dark chestnut virgin soils in horizon A is 3.7 (Table 3). Arable soils are characterized by a decrease in the structural coefficient to 1.5. The number of lumpy particles increases to 30%, and valuable aggregate content decreases to 60.2%. The deterioration of the structure of arable soils is probably due to the annual impact of tillage machinery. Fallow lands, after seven years of natural recovery, show improved structural properties, with an increase in the structural coefficient to 2.2 and a 6% reduction in lumpiness. The study of the density of fallow land, arable land, and virgin lands showed that these soils are compacted according to the Kachinsky gradation. On fallow land and arable land, the soil density reaches its highest values of 1.32 and 1.34g/cm2 (Fig. 3).

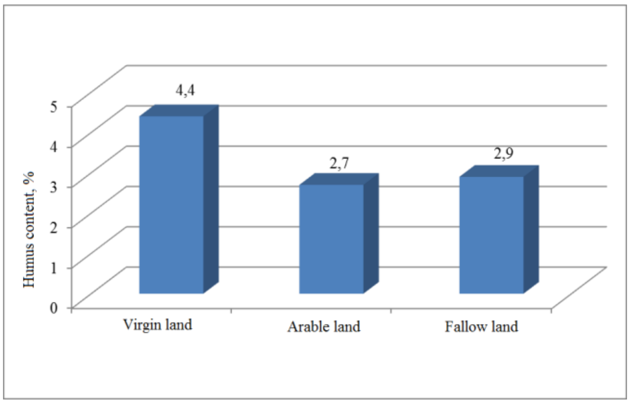

Fig. 2: Humus content (%) in horizon A.

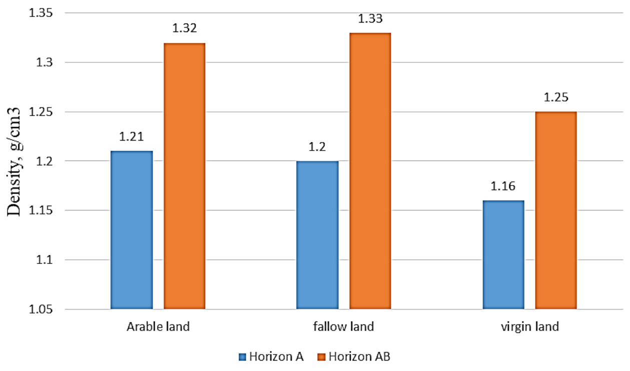

Fig. 3: Changes in soil density in dark chestnut soils at different tillage depths.

Table 3: Structural composition (5) of dark chestnut soil

Agricultural land	Horizon, layer (cm)	Size of the units (mm)			Kstr
		>10	10-0.25	<0.25	
Arable land	Aar, 0-16	30.0	60.2	9.3	1.5
7-year-old fallow land	A, 0-17	24.0	67.5	7.5	2.2
Virgin land	A, 5-22	15.0	78.7	6.3	3.7

In the upper horizons of fallow soils, under the influence of vegetation, significant decompression occurs up to 1.20g/cm3. However, long-term agricultural use of arable soils leads to compaction of their subsurface layer. The search for optimal agricultural methods of fallow soil tillage was conducted on three sites, following the approved design in August 2018, 2019, and 2020. The following year, the soil in these areas was considered black fallow. After black fallow, winter wheat and winter wheat with the addition of perennial grasses were sown. The tillage methods significantly influenced the water regime and determined the further use of these lands. This is evidenced by the data in Table 4. The data on moisture reserves in the year of plowing did not show significant changes in the water regime, since, first, autumn precipitation was poorly accumulated by treated dry soil and, second, the fallow land tillage in the second half of summer, including two-fold tillage of the sod with disk tools, and then the main tillage, contributed to loosening and drying of the soil not only in the arable layer but also partially in the sub-arable horizons of the soil.

Deep tillage (by 25-27cm) results in the accumulation of from 25-30 to 55-60% of autumn-winter precipitation moisture by the soil (Table 4). The fallow land after tillage does not have enough moisture from the autumn-winter precipitation period. As a rule, a dry layer forms on such soils by spring. Against the background of moldboard plowing in the black fallow field in the second autumn-winter period, the dry layer was eliminated. The reserves of productive moisture in the 0-150cm layer reached an average of 125.5-146.6mm. Accordingly, moisture reserves in the soil had increased significantly compared to the autumn of the previous year. Therefore, sowing should be carried out after a year of black fallow. The benefits of deep plowing during the black fallow period as a way to improve the water regime and increase yields have been confirmed (Zhao et al., 2021; Li et al., 2022).

During moldboard plowing, moisture accumulated more actively and penetrated deeper layers compared to boardless plowing by 15%. After loosening at a depth of 14-16cm, the dry layer in the 100-130cm layer did not disappear. Thus, after plowing a long-term fallow land, there was a significant improvement in the water regime of the soil. Deep basic tillage allows moisture to penetrate the profile at a depth of 130-150cm, thereby eliminating the dry layer of fallow soils. In the black fallow/grain field crop rotation, moldboard plowing against the background of black fallow had a positive effect on the water regime, since the depth of soaking increased and the dry layer of soil disappeared. Many researchers noted an increase in grain yields and the availability of nutrients in the soil with the use of deep basic tillage and, conversely, a decrease in the yield of forage and grain units with a decrease in the tillage depth (Dang et al., 2016; Popov et al., 2019; Pakul et al., 2021; Rzaeva, 2021; Zhao et al., 2021). The densification of fallow and plowed soils did not differ much (Table 5). The plowed fallow land was characterized by greater densification associated with the action of agricultural machinery. Against the background of tilling at 25-27cm, the soil density at a depth of 10cm was 1.22-1.26g/cm3, and at a depth of 30cm, it was 1.30-1.33g/cm3. Against the background of fine loosening, the soil was compacted more strongly: at a depth of 10cm its density reached 1.26-1.28g/cm3, and at a depth of 30cm it was 1.34g/cm3. The presence of more compacted soil is explained by the non-destroyed old plow sole.

Table 5 showed the soil density data determined in the crops of perennial grasses of the first and second years of use. The data show that a larger density at a depth of 10 and 30cm is detected against the background of fine loosening. Compared to spring wheat crops, the soil density under perennial grasses is lower. The decrease in the density of soil composition is influenced by the age of grasses and a powerful root system that improves the structure of soils.

Thus, the density of the dark chestnut soil improves with moldboard or boardless tillage at a depth of 25-27cm. Fine loosening does not ensure the destruction of the plow sole and a decrease in density, thereby preventing the accumulation and penetration of moisture into the underlying soil layers. Fine tillage has a negative aftereffect in crop rotations with annual crops and in the reserve field with perennial grasses. Despite the dry conditions during the study period, the three-year data revealed the impact of basic fallow tillage methods on productivity. Moldboard plowing at a depth of 25–27cm consistently resulted in the highest spring wheat yields, which were recorded as 0.81, 0.46, and 0.21t/ha over the three study years. High soil moisture availability and a sufficient amount of available nutrients ensured the effectiveness of this tillage system (Table 6).

The fallow land tillage with a blade cultivator at a depth of 25-27cm was as effective as the variant with moldboard plowing at the same depth. Only in 2020, in the variant with moldboard plowing, the yield was higher by 0.05 t/ha. In the variant with fine loosening at a depth of 14-16cm, the yield of spring wheat decreased by more than 30%. The yield of the grass mixture in the variants with deep tillage also was higher than in the variants with fine loosening. In the first year of use (the second year of life), a grass mixture of wheatgrass and alfalfa against the background of deep tillage yielded a hay harvest of 1.14t/ha. In the variant with fine loosening, the hay yield was 1.5 times less (0.79t/ha). In the second year of use (the third year of life),

Table 4: Reserves of available moisture (mm) in the cultivated fallow dark chestnut soil in the black fallow/grain link of crop rotation

Main method of tillage during the development of fallow land	Years	Soil layers (cm)			
		0-50	50-100	100-150	0-150
When leaving for winter in the year of development of the fallow land					
Plowing at a depth of 25-27cm	2018-2020	21.0	-12.1	0.2	9.1
Tillage with a blade cultivator at a depth of 25-27cm		22.0	-12.1	0.6	10.6
Loosening at a depth of 14-16cm		5.8	-16.1	-1.5	-11.8
Least Significant Difference (LSD)05		2.5	0.6	1.0	1.7
In the spring in the black fallow field					
Plowing at a depth of 25-27cm	2019-2021	89.9	20.4	5.7	116.0
Tillage with a blade cultivator at a depth of 25-27cm		85.9	15.6	3.3	104.8
Loosening at a depth of 14-16cm		87.6	-0.2	0.9	88.3
LSD05		1.9	2.9	1.4	3.8
When leaving for the winter in the black fallow field					
Plowing at a depth of 25-27cm	2019-2021	83.7	27.6	9.2	120.5
Tillage with a blade cultivator at a depth of 25-27cm		83.4	17.0	4.8	105.2
Loosening at a depth of 14-16cm		85.3	3.7	1.5	90.5
LSD05		1.7	2.7	1.4	2.8
In spring, when sowing spring wheat					
Plowing at a depth of 25-27cm	2020-2022	92.2	33.9	20.5	146.6
Tillage with a blade cultivator at a depth of 25-27cm		92.9	22.0	10.6	125.5
Loosening at a depth of 14-16cm		83.7	11.0	2.7	97.4
LSD05		1.2	2.4	3.3	5.6

Table 5: The effect of plowing fallow land on the density of dark chestnut soils (g/cm3) when sowing spring wheat

Basic tilling during plowing of the fallow land	Sampling depth (cm)	2020	2021	2022
Fallow land (control)	10	1.19	1.18	1.16
	30	1.33	1.32	1.31
PN-4-35 at a depth of 25-27cm	10	1.23	1.22	1.23
	30	1.32	1.31	1.30
KPG-250 at a depth of 25-27cm	10	1.25	1.26	1.26
	30	1.33	1.33	1.32
PN-4-35 at a depth of 14-16cm (loosening)	10	1.27	1.26	1.28
	30	1.34	1.34	1.34
LSD05	10	0.04	0.03	0.05
LSD05	30	0.03	0.04	0.04
Basic tilling during plowing of the fallow land		Grass mixture, t/ha of hay		Grass mixture of the second year of use
		2021	2022	2022
Fallow land (control)	10	1.18	1.16	1.16
	30	1.32	1.31	1.31
PN-4-35 at a depth of 25-27cm	10	1.11	1.13	1.10
	30	1.20	1.22	1.19
KPG-250 at a depth of 25-27cm	10	1.14	1.16	1.11
	30	1.23	1.24	1.20
PN-4-35 at a depth of 14-16cm (loosening)	10	1.20	1.22	1.23
	30	1.33	1.35	1.35
LSD05	10	0.05	0.05	0.05
LSD05	30	0.05	0.05	0.08

Table 6: The effect of the basic fallow land tillage methods on the yield of spring wheat and grass mixtures

Main method of tillage during the development of fallow land	Spring wheat, t/ha of grain			
	2020	2021	2022	Average
Plowing at a depth of 25-27cm	0.81	0.46	0.21	0.49
Tillage with a blade cultivator at a depth of 25-27cm	0.76	0.44	0.19	0.46
Loosening at a depth of 14-16cm	0.52	0.31	0.14	0.32
LSD05	0.02	0.05	0.01	0.05
Main method of tillage during the development of fallow land	Grass mixture, t/ha of hay			
	1st year of use			2nd year of use
	2021	2022	average	2022
Plowing at a depth of 25-27cm	1.21	1.07	1.14	2.12
Tillage with a blade cultivator at a depth of 25-27cm	1.15	1.13	1.14	1.99
Loosening at a depth of 14-16cm	0.86	0.72	0.79	1.35
LSD05	0.04	0.08	0.08	0.18

the productivity of perennial grasses doubled. In 2022, against the background of deep tillage, the yield of hay was 2.12t/ha. Against the background of boardless deep tillage, the hay yield was 1.99t/ha, i.e., slightly lower than in the variant with plowing. Against the background of fine loosening, the hay yield was 1.35t/ha, i.e., two times lower than in variants with deep basic tillage. The aftereffect of deep tillage of the fallow land persists into the third year of the life of the grasses. Alfalfa accounted for 70-75% of plants in the grass mixture in the first year. In the second year of use, the share of alfalfa reached 35-40%, and the share of wheatgrass increased to 60-65%. The high tilling capacity of the wheatgrass provided optimal projective soil coverage. The productivity of haymaking over time was maintained using a grass mixture, rather than pure crops of wheatgrass and alfalfa.

Thus, moldboard and boardless tillage of fallow land at a depth of 25-27cm was more effective than the variant with fine loosening. In the variants with deep tillage, the yield of spring wheat and grass mixtures became 30 and 55%

Table 7: The effect of basic tillage methods and links of crop rotations on the productivity of cultivated fallow dark chestnut soil, tons of grain units on average per 1 ha of crop rotation area, average for 2019-2022

Main method of tillage during the development of fallow land (factor A)	Crop rotation links (factor B)		Average factor A LSD05=0.02
	black fallow – spring wheat	black fallow – spring wheat + grasses – grasses of the 2nd-3rd years of life	
Plowing at a depth of 25-27cm	0.24	0.16	0.20
Tillage with a blade cultivator at a depth of 25-27cm	0.23	0.15	0.19
Loosening at a depth of 14-16cm	0.16	0.10	0.13
Average for the LSD05 factor = 0.018	0.21	0.14	0.17
For comparison of particular average LSD05 = 0.03			

higher, respectively. Using perennial grasses in the first year of development of fallow land can cover the needs for animal forage. To study the mutual influence of factors on the productivity of fallow soils, we carried out a two-factor analysis of variance. This analysis showed the role of deep basic tillage and the advantage of black fallow in developing fallow dark chestnut soils (Table 7). The reliability of each studied factor was confirmed statistically. The actual values of the Fisher criterion were 42.5 and 134.6, with theoretical values of 3.6 and 4.4.

DISCUSSION

This study highlights the significant effects of various tillage methods on the productivity and soil properties of fallow dark chestnut soils in northwestern Kazakhstan. Our research agrees with the current research trend that aims to identify favourable conditions to improve the productivity of fallow dark chestnut soils due to their unique nature consisting of shallow humus layers and unfavorable water regimes (Zhulanova et al., 2020; Rau et al., 2023). Moldboard plowing has been reported to increase moisture supply, decreased density, and increased availability of nutrients, such as nitrogen and potassium (Pakul et al., 2021; Popov, 2019). Our results showed that deep moldboard and boardless tillage systems significantly improve soil water retention, nutrient availability, and crop yields. These finding are consistent with the works of Gostev et al. (2019), who proved that the moldboard tillage system displayed the best results in their measured parameters. On the contrary, Zakaria (2023) claimed that deep plowing with moldboard plow had an adverse effect on soil health and quality parameters but showed higher disease resistance and pest growth. Our results agree with Ghali et al. (2019), who concluded that moldboard systems increased soil water retention, but this differed with distance. The works of Seminchenko (2021) and Kuzychenko (2021) also confirm the finding that moldboard and boardless tillage systems increase the density of dark chestnut soils. The negative aftereffect of fine tillage was supported by the works of Kutilkin et al. (2020), Rzaeva (2021) and Hofbauer et al. (2022) noted that there was a reduction in crop yield and soil nutrient availability and soil water retention under shallow tillage in comparison with other tillage systems. This information is crucial for farmers in arid regions, where maximizing water use efficiency is critical. Our study demonstrates that in terms of biological soil activity and fertility restoration, the increase in soil nutrients observed in fallow soils aligns with the findings of Nunisa et al. (2023). We extend these findings by showing that biological activity was 1.5 times higher in fallow soils compared to arable soils, highlighting the significant potential of fallow land management for long-term soil restoration.

While our study supports the efficacy of deep tillage, it also underscores the importance of integrating perennial grasses into crop rotation systems. The incorporation of alfalfa and wheatgrass, which resulted in increased hay yields, aligns with the works of Francis and Clegg (2020), highlighting the crucial role of diverse crop rotations in improving soil health and productivity. This study provides evidence that deep tillage, coupled with black fallow management and the use of perennial grasses in crop rotation, is essential for optimizing the productivity and ecological sustainability of fallow dark chestnut soils. These findings complement and expand upon prior research, offering practical recommendations for addressing agricultural challenges in similar arid and semi-arid regions. Future studies should explore the long-term economic impacts of these practices to validate their viability for widespread adoption further.

Conclusion

The fallow dark chestnut soils of the northwest of Kazakhstan by the age of 8 years become close to virgin soils in basic fertility indicators. The main indicator of low productivity of fallow lands is an extremely unfavorable water regime, characterized by a low coefficient of moisture absorption from precipitation and shallow wetting of the horizons, leading to the formation of a dry layer and low vegetation productivity. Deep basic tillage of fallow soils in combination with black fallow contributes to the accumulation of moisture and increases the yield of spring wheat and grass mixtures. Productivity indicators were much lower in all variants of the experiment with fine soil loosening. Therefore, when developing the fallow dark chestnut soils of the northwest of Kazakhstan, preference should be given to moldboard plowing, since it provides a slightly better water regime for the soil than boardless tillage. This does not detract from the importance of boardless tillage for soil protection, since in the experiments, the effectiveness of these two soil tillage methods was compared, first, against the background of the need to cut the sod of the fallow land and, second, against the background of a year and a half of black fallow.

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Sarsengaliyev – reviewing the manuscript, editing; N.Kh.Utegaliyeva – methodological development. All authors have been preparing a draft of the manuscript, revised and approving the last version of the article.

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