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Influence of tillage methods on food security and its agrophysical and water-physical properties

Askar RZALIYEV[1*], Valeria GOLOBORODKO[1], SHABDEN BEKMUHAMETOV[1], Zhumagali OSPANBAYEV[2], Aizada SEMBAYEVA[2]

Abstract

To maintain the pace of the agriculture industry and assist bridge the gap between food supply and demand, best-implemented, sustainable, and optimal solutions are needed. Soil and water resources, research and development, extension, agricultural education, and related infrastructure development must be prioritized to boost food production and enhance soil and water management. Research has been carried out on the effect of various methods of main tillage - chiseling with various types of chisel rippers and moldboard plowing - on the agro- and water-physical parameters of light chestnut soil. Differences in soil density and moisture levels have influenced the development of corn plants. On the variants with deep chisel tillage, the accumulation of dry and raw plant biomass and the yield of corn grain were higher. Thus, the methods of main tillage allow to regulate the agro- and water-physical state of the soil and to have a significant effect on the productivity of plants. On the basis of the data obtained, for high-quality main tillage, providing optimal indicators of its density, crumbling, reserves of total and available moisture in the soil, it is possible to recommend the use of an experimental chisel ripper CR-2.4.

Keywords: agrophysical soil parameters; moisture reserve; corn plants; food production.

Practical Application: The practical significance of the research lies in determining the methods of tillage that contribute to an increase in soil moisture reserves and crop productivity.

1 Introduction

Maintaining our soil's health and productivity while conserving the environment is critical for agriculture as the world's population grows and food production demands increase (Singh et al., 2018). The world's growing population is putting enormous strain on the restricted land area and resources available for agricultural production, and looming climatic extremes are exacerbating the problem of food security in both rich and developing countries (Nakat & Bou-Mitri, 2021). Conservation agriculture is also climate-smart agriculture, making the shift to farming more resilient to the effects of climatic extremes that threaten food security. We can no longer afford to separate food security from natural resource security (Ker, 2020). In the conditions of South-East Kazakhstan, the main limiting factor in obtaining high yields of agricultural crops is the presence of soil moisture. With a high sum of positive temperatures on serozem and light chestnut soils, the average long-term rainfall per season is 200-300 mm, while the amount of evaporation from the soil surface reaches 700-900 mm/year. Such a significant loss of moisture leads to drying up of soils, an increase in water consumption for irrigation (Hecht et al., 2019).

An increase in soil moisture supply can be achieved through irrigation, increased water-holding capacity, and decreased moisture evaporation from the surface. The main constants characterizing the water regime of soils are the total moisture reserve and the productive moisture reserve (Riaz et al., 2020; Rigden et al., 2020).

One of the techniques allowing to influence the water balance of the soil is its mechanical cultivation, which, through the effect on the agrophysical parameters of the soil, the density, fractional composition helps to increase its water-holding capacity, prevent water runoff during snow melting and precipitation, as well as soil washout. The creation of a finely lumpy mulch layer on the surface prevents the unproductive consumption of moisture through its evaporation from the surface (Karavani et al., 2018).

Learning how agriculture responds to moisture and heat stress is crucial for food system adaptation in the face of weather patterns change. While there is plenty of proof of agricultural yield loss owing to increasing heat, separating the effects of moisture and temperature in determining yield has proven difficult, owing to a lack of soil moisture data and the close connection between temperature and moisture at the land area (Rai, 2020; Sattar et al., 2020). Numerous studies have shown that the supply of productive moisture in the soil depended on its type, methods of cultivation, the depth of cultivation, and the time of its implementation (de Lima et al., 2021; Mesterházy et al., 2020). According to Burtseva et al. (2021), on light chestnut soils of the Lower Volga region, the most favorable water regime is formed with non-moldboard tillage with subsurface cultivators and SibIME stands while maintaining the maximum amount of stubble, which contributes to the complete assimilation of precipitation. Due to the deterioration of the water regime,

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[1] Limited Liability Company, Scientific and Production Center of Agricultural Engineering, Almaty, Kazakhstan
[2] Limited Liability Company, Kazakh Research Institute of Agriculture and Plant Growing, Almaty, Kazakhstan
*Corresponding author: rzaliyev@mail.ru

shallow soil cultivation can be used in combination with periodic deep or other methods of decompaction of the lower soil layers, primarily in years with its low autumn moisture load.

The soils of the South-East of Kazakhstan differ from the soils of the Lower Volga region in less moisture supply due to higher summer-autumn temperatures and less precipitation, as well as a wide variety of mechanical composition: from sandy loam (serozem); to heavy loamy (chestnut soils) (Suleimenova et al., 2021).

In this zone, the main applied tillage technology is traditional, which accounts for 90% of all cultivated crops. A feature of this technology is the use of moldboard plowing in autumn or spring.

The negative impact on the soil's agro- and water-physical state begins with moldboard plowing (Zakharov & Morgacheva, 2020). As a result of its prolonged use, enhanced mineralization of organic matter occurs, the soil is quickly "plowed out," heavily sprayed, a plow sole is formed, the formation of which occurs both under the influence of the working organs of arable aggregates, and as a result of systematic over compaction by all types of machine-tractor tillage aggregates (MTA).

Due to the blockage of soil cracks and inter-aggregate space, a water-resisting and waterproof layer is formed in this zone, which can subsequently cause waterlogging in micro depressions in the form of "saucers," which causes the manifestation of erosion processes by forming surface runoff in fields even with a slight slope. Over consolidated soil dramatically reduces its water-absorbing property (Hendrickson, 2015). Studies show that assimilation of atmospheric precipitation by compacted soil decreases three to four times, and with irrigation, this difference can be an order of magnitude higher (Darko et al., 2020; Pismennaya et al., 2020). Row crops are especially sensitive to the presence of plow soles in the soil. Chisel rippers are used to loosening the soil to a depth of 40 cm. A number of foreign authors have studied the mechanism of the effect of various types of tillage on its productivity (Wang et al., 2020; Yadav et al., 2019; Zulfiqar et al., 2020). Chisel loosening of the soil occurs under the influence of a chisel and wings (deformers). Depending on the moisture content of the soil, the volume occupied by the subsoil ridges formed in the inter-track of the working bodies of the chisels reaches 60%. With an insignificant amount of autumn precipitation in the south of Kazakhstan, accounting for 20% of the annual norm, the subsoil ridges are not completely destroyed by the beginning of spring fieldwork. The presence of subsoil ridges with a soil density of 1.5-1.6 g/cm3 and a plow sole impairs the quality of pre-sowing tillage and inhibits the development of the root system of plants. So, according to scientists, the shortage of harvest in the fields due to the oppressive effect of the plow sole and subsoil ridges can be 30-40%, which predetermines the need to develop chisel rippers carrying out continuous loosening of the soil to a depth of 35 cm.

For the implementation of promising soil-saving technologies for the cultivation of agricultural crops, it is necessary to conduct research on the influence of various methods of main tillage on the agrophysical and water regime of soils in this region.

The research aims to determine the influence of the methods of main tillage on its agrophysical properties, water regime, and corn productivity.

2 Research methods

Water level variations commonly affect food availability since they induce changes in fish-eating patterns and predator-prey interactions, generally by boosting piscivory during drawdowns. Drawdowns may push tiny or immature fish to leave the nearshore zone, subjecting them to pelagic predation, much as they do for invertebrates (Salama et al., 2021). Variations in food webs can result from changes in the availability of food and trophic interactions. Work on the study of the water regime of light chestnut soil was carried out in 2018-2020 on the fields of the LLP "KazRIAPG." On the experimental-production site using the technology of growing corn for grain with drip irrigation, a Moldovan hybrid of corn - Porumben 458 was sown.

The water regime of soils was studied with the following methods of its tillage:

- moldboard plowing with a reversible plow SRP-4-40 to a depth of 25 cm;
- chiseling the soil to a depth of 35 cm with its continuous cultivation with a serial chisel plow CP-2.5;
- chiseling the soil to a depth of 35 cm with its continuous cultivation with an experimental chisel ripper CR-2.4.

Agrophysical indicators of soil: density, crumbling, moisture was determined according to GOST 33736-2016 "Agricultural machinery. Deep tillage machines. Test methods". Interstate standard. GOST 33687-2015 "Machines and tools for surface tillage. Test methods". Interstate standard. The indicators of the water regime of soils were determined by the following Formulas 1-3 [22].

$$H = A \times \rho\ h, \tag{1}$$

Where H - total moisture reserve, t/ha;

A – soil moisture in % to absolutely dry sample;

ρ – soil density, g/cm3;

h – thickness of the studied layer, cm.

To express water reserves in millimeters of the water column, the received amount of water in tons per hectare was divided by 10. The formula calculates unavailable moisture reserve:

$$H_{un}, t/ha = W_{mh} \times k \times \rho \times h \tag{2}$$

where Wmh – the maximum hygroscopicity of soil, %;

k – coefficient that depends on the particle size distribution of the soil. For light chestnut soils, it is 1.4;

ρ – soil density, g/cm3;

h – thickness of the studied layer, cm.

The reserve of available soil moisture is determined by subtracting the unavailable moisture reserve from the total amount of water in the soil. The calculation was carried out according to the following formula:

$$H_{av.} = H_{tot.} - H_{un.}, \ t / ha \qquad (3)$$

3 Results and discussion

Food security is dependent on long-term, high-yield agricultural production, especially in the face of climate change. Soil management techniques that enhance soil function, soil quality, and soil health are required for the long-term sustainability of high agricultural yields (Abdullah, 2019; Chen & Yu, 2021). Adaptive management as a preventative aspect of water and soil conservation is gaining considerable international attention against the backdrop of an intensification of agriculture utilizing the same land footprint to satisfy the rapidly expanding demand for food (Łabędzki, 2016). The studies were carried out at the site LLP "KazRI of agriculture and plant growing" in 2017-2019 on light chestnut soil of medium loamy texture. The selection of samples to determine the soil's agro- and water-physical properties was carried out after harvesting winter wheat in 2017 and in the spring of 2018 before cultivation. The main characteristics are shown in Table 1.

According to the data given in the table, in the autumn period in the upper soil layers (0-20 cm), the density averaged 1.15 g/cm3, while in the layers 20-40 cm, it reached 1.46 g/cm3. This increase in density is due to the presence of a plow sole, which is located in these layers. Compaction of 20-40 cm soil layers was also preserved in the spring since the plow sole did not loosen up due to the insignificant precipitation in winter.

To determine the influence of various types of main tillage, in October 2017, an experiment was laid on the stubble background in which the soil was loosened with commercially available tools: a chisel plow CP-2.5 to a depth of 35 cm and a reversible plow SRP-4-40 to a depth of 25 cm.

When loosening the soil with CP-2.5, the indicator of the crumbling efficiency or the volume of loosening the soil in the inter-track was 68%. The rest of the volume fell on uncultivated soil - subsoil ridges into which deformation from the action of working bodies does not extend. Figure 1 shows the dynamics of soil density by the depth of cultivation and by the width of the spacing of the working bodies. Figure 2 shows the soil profile after passing the CP-2.5 (Figure 3).

In the spring of 2018, on all options of the experiment, the same pre-sowing tillage was carried out to a depth of 12 cm, including early spring closing of moisture with a soil spiker HSS-3; loosening, leveling, and packing of the soil with a combined tool CT-3.6, developed by "SPC AE" LLP. After pre-sowing tillage, the agrophysical parameters of the soil were determined before sowing corn (Table 2).

According to the data given in the table, the soil density during chiseling in the upper layers was slightly higher due to

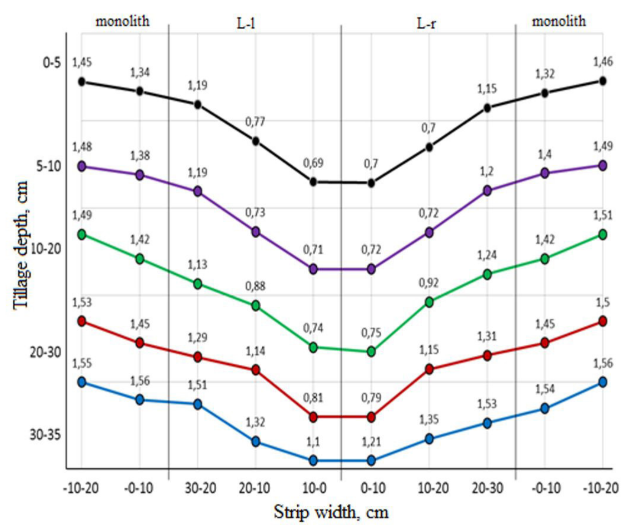

Figure 1. Soil density (g/cm3) in the inter-track of the chisel ripper.

Table 1. Agro- and water-physical indicators of light chestnut soil.

Indicators	Soil layers							X
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	0-70
Maximum field moisture capacity. %	20.0	21.0	22.0	22.3	23.6	23.8	24.0	22.4
Mechanical composition (clay content in %)	Medium loamy (32.7%)							
October 14, 2017								
Moisture. %	12.0	12.8	13.1	13.6	14.7	14.8	14.5	13.7
Total moisture reserve. mm	13.2	15.4	18.3	20.6	22.0	22.2	21.9	19.1
Density. g/cm3	1.1	1.2	1.40	1.52	1.50	1.50	1.51	1.39
Hardness	2.0	2.5	2.7	2.8	2.9	3.0	3.2	2.7
April 15. 2019								
Moisture. %	16.7	17.0	17.9	18.0	17.9	17.8	17.5	17.5
Total moisture reserve. mm	16.4	17.0	22.9	24.8	25.4	25.6	25.0	22.4
Density. g/cm3	0.98	1.0	1.28	1.38	1.42	1.44	1.43	1.28
Hardness	1.3	1.5	1.6	1.8	1.90	1.92	1.95	1.37

Table 2. Influence of various types of main tillage of light chestnut soil on its agrophysical indicators.

Options	Soil crumbling. % by fractions. mm				Soil density. g/cm^3			
	>50	50-20	20-10	<10	0-10	10-20	20-30	30-35
Autumn chisel tillage (CP-2.5) + pre-sowing tillage	5.7	30.0	35.6	28.7	1.0	1.15	1.18	1.25
Autumn moldboard tillage (SRP-4-40 + pre-sowing tillage)	7.0	34.3	33.9	24.8	0.90	0.95	1.35	1.48

Figure 2. Subsoil ridges formed by chisel plow CP-4.5.

the presence of subsoil ridges. However, there were no sharp changes in its values in the soil layers. Its fluctuations ranged from 1.0 g/cm3 in layers of 0-10 cm to 1.25 g/cm3 in layers of 30-35 cm. When plowing in layers of 20-35 cm, there was a sharp increase in soil density to 1.35-1.48 g.

The main indicator of the quality of pre-sowing tillage is its crumbling. According to the data given in Table 2, the content of soil lumps is larger than 50 mm. It was higher against the background of moldboard plowing, and soil crumbling was better on the option with chisel tillage. However, the crumbling indicators did not meet the agricultural requirements for all options of the experiment since, before sowing, the content of soil fractions larger than 50 mm was more than the permissible 5%, and fractions smaller 20 mm less than the permissible 70%. The insufficient crumbling of the soil in the option with chiseling is associated with the presence of subsoil ridges, which, due to their increased hardness, are poorly destroyed during cultivation.

The study of the water regime of the soil after the pre-sowing tillage showed that the penetration of precipitation into the soil and the accumulation of moisture in it is hindered by both subsoil ridges during chisel tillage and the plow sole during plowing. The data on the stock of total and available moisture for the variants of the experiment are presented in Table 3.

When chiseling, the reserve of total and available moisture was slightly higher. To destroy subsoil ridges and improve the agrophysical parameters of the soil, we have developed a working body of a chisel ripper and a chisel ripper CR-2.4, which provides continuous loosening of the soil without leaving subsoil ridges to a depth of 35 cm (Figure 4-5).

Figure 3. Chisel plow CP-4.5.

In autumn 2018, to the field experience laid down in 2017, an option was added in which the main tillage was carried out with an experimental chisel ripper CR-2.4 (Figure 4). In the spring of 2019, at the same time, on all variants of the experiment, pre-sowing tillage was carried out according to the scheme given above, followed by sowing of corn. The studied options for the main autumn tillage had a different effect on soils' agrophysical state and water regime, particularly on crumbling, density, and the reserve of moisture in the soil, both total and available (Table 4). Changes in the agrophysical parameters of the soil were traced up to the harvesting of corn. Soil samples for research were taken during the emergence of corn and after harvesting.

Table 3. The content of reserves of total and available moisture in the soil after chiseling and plowing.

Soil layers	Autumn chisel tillage CP-2.5 + pre-sowing tillage		Autumn moldboard tillage SRP-4-40 + pre-sowing tillage	
	Reserve of total moisture. mm	Reserve of available moisture. mm	Reserve of total moisture in soil layers. mm	Reserve of available moisture. mm
0-10	11.2	5.7	9.4	5.1
10-20	14.9	7.0	12.0	6.3
20-30	18.4	10.6	15.9	8.0
30-40	20.7	11.8	17.2	12.8
40-50	21.0	12.8	17.8	14.0
0-50	73.5	47.9	72.3	46.2

Figure 4. Soil profile after passing CR-2.4.

According to the data obtained, the minimum value of the soil density by layers at the beginning and end of the growing season of corn was in the option with its continuous cultivation with CR-2.4. At the chisel plow CP-2.5 and the reversible plow SRP-4-40, the soil density was slightly higher due to the presence of subsoil ridges after chiseling and plow soles after plowing. The presence of plow sole and subsoil ridges was traced until the end of the corn growing season. For the same reasons, the crumbling of the soil corresponded to agrotechnical requirements only when the soil was cultivated with a chisel ripper CR-2.4. Changes in agrophysical properties under the influence of various types of main tillage influenced the availability of reserves of total and available moisture in the soil (Table 5).

The minimum amount of total and available moisture in the soil before sowing and after corn harvesting was noted for the option with autumn plowing, and the maximum amount for the option with chiseling the soil CR-2.4. On this option, when sowing corn, the amount of total and available moisture was, respectively, 20 and 16.7% higher; after harvesting corn, these indicators were 18.5 and 17.0%, respectively. In general, the moisture reserve in the soil by the end of the growing season decreased due to the cessation of irrigation, high temperatures, contributing to evaporation from the soil surface, and lack of precipitation.

Figure 5. Chisel ripper CR-2.4.

The presence of subsoil ridges and plow soles through the impact on the agrophysical and water-physical parameters of the soil influenced the development of plants. So, the best development of the root system and the plants, in general, was

Table 4. Influence of various types of main tillage of light chestnut soil on its agrophysical indicators.

Indicators	Autumn chisel tillage CP-2.5 + pre-sowing tillage		Autumn chisel tillage CR-2.4 + pre-sowing tillage		Autumn moldboard tillage SRP-4-40 + pre-sowing tillage	
	Research date					
Soil density by layers. g\cm^3	01.05.2019	03.09.2019	01.05.2019	03.09.2019	01.05.2019	03.09.2019
0-10	1.0	1.1	0.98	1.10	0.98	1.0
10-20	1.08	1.12	1.03	1.10	1.16	1.20
20-30	1.23	1.30	1.14	1.20	1.32	1.38
30-40	1.41	1.45	1.25	1.34	1.55	1.58
40-50	1.47	1.51	1.48	1.50	1.54	1.56
On average in layer 0-50	1.24	1.30	1.17	1.25	1.31	1.34
Soil crumbling. % by fractions. mm						
>50	6.0	-	4.2	-	7.1	-
50-20	29.5	-	23.7	-	31.7	-
20-10	35.6	-	37.0	-	34.6	-
<10	28.9	-	35.1	-	26.6	-

Table 5. Analysis of reserves of total and available moisture in the soil for various methods of its cultivation.

Soil layers. cm	Autumn chisel tillage CP-2.5 + pre-sowing tillage		Autumn chisel tillage CR-2.4 + pre-sowing tillage		Autumn moldboard tillage SRP-4-40 + pre-sowing tillage	
	Moisture reserves. mm					
	total	available	total	available	total	available
Emergence of seedlings (May 1)						
0-10	13.7	8.2	14.3	8.6	12.0	7.2
10-20	15.2	9.1	17.1	10.3	14.8	8.9
20-30	19.4	11.6	22.3	13.4	16.0	11.6
30-40	23.1	13.9	24.9	14.9	20.1	12.1
40-50	24.1	14.5	24.9	14.9	19.9	11.9
∑0-50	95.5	57.3	103.5	62.1	82.8	51.7
Corn harvesting (September 3)						
0-10	12.2	7.32	13.3	8.0	12.0	7.2
10-20	13.7	8.22	16.8	10.1	13.5	8.1
20-30	18.0	11.4	18.7	11.2	15.4	10.2
30-40	21.5	13.5	23.4	14.0	18.7	11.2
40-50	20.7	12.4	24.1	14.5	18.9	11.3
0-50	86.1	52.8	96.3	57.8	78.5	48.0

Autumn chisel tillage CP-2,5 + pre-sowing tillage; Autumn moldboard tillage SRP-4-40 + pre-sowing tillage.

noted with continuous autumn loosening of the soil with the chisel ripper CR-2.4 (Figure 6), which later affected the yield.

Figure 7 shows the corn plantings in the field experiment.

Indicators of the productivity of corn are given in Tables 6 and 7. According to the data presented, on the variants with deep chisel processing CP-2.5 and CR-2.4, the accumulation of dry and raw plant biomass and the yield of corn grain were higher. On average, over two years, the dry weight of ten plants in the phase of full ripeness for moldboard plowing SRP-4-40 was 1376 g, for CP-2.5 - 1491 g, for CR-2.4 - 1532 g.

The increase in the grain yield of corn according to the option with soil chiseling CP-4,5 in comparison with plowing, on average for two years, amounted to 7.2 dt/ha; according to the option with chiseling CR-2.4 - 17.1 dt/ha.

Thus, the methods of main tillage allow regulating the agro- and water-physical state of the soil and have a significant impact on the productivity of corn. The most promising method of tillage is its continuous chisel loosening to a depth of 35 cm without leaving the subsoil ridges with the chisel ripper CR-2.4.

Figure 6. Influence of different methods of main tillage on plant development.

a b

a b

Figure 7. Development of corn with different tillage methods. a - autumn moldboard tillage (SRP-4-40 + pre-sowing tillage CT-3.6; b - autumn chisel tillage CR-2.4 + pre-sowing tillage CT-3.6.

Table 6. Accumulation of raw and dry biomass of corn plants depending on the tillage methods.

Tillage methods	Raw/dry weight of 10 plants. g				
	Development phases of plants				
	Five leaves	ear formation	flowering	milky-wax ripeness	full ripeness
		2018			
Moldboard plowing SRP-4-40	987	5012	5781	6211	5117
	541	2403	3425	4055	1268
Deep loosening CP-4.5	1210	5334	6041	6432	5671
	640	2541	3425	4284	1485
		2019			
Autumn plowing SRP– 4– 40	845	4230	6125	6566	4973
	356	1782	2158	2355	1485
Deep loosening CP-4.5	860	4.520	6300	6680	5100
	330	1880	2200	2720	1497
Soil chiseling CR-2.4	890	4751	6481	7254	5346
	410	1965	2287	3566	1532

Table 7. Yield and moisture content of corn hybrid Porumben 458, 2018-2019.

Main tillage methods	Plant height. cm		Grain yield. dt/ha		
	2018	2019	2018	2019	On average. for two years
Moldboard plowing SRP-4-40	200.0	207.0	115.0	101.3	108.2
Soil chiseling CP-4.5	215.7	212.4	120.0	110.8	115.4
Soil chiseling CR-2.4	223.3	220.1	-	125.3	125.3
LSD05 -3.7 dt/ha					

4 Conclusion

A perceptible food crisis has seized public attention throughout the world in the last year or so, in connection with an increasingly apparent energy scarcity and global warming. The end of the age of cheap food has been heralded by rising food costs and a wave of food riots. Measures to stabilize and improve soil productivity must be implemented as soon as possible to help accomplish the main goals of development cooperation, reduced poverty, food security, and sustainable natural resource management. On the other hand, traditional tillage practices increase soil deterioration and, as a result, diminish soil production. It has been established that after plowing in a layer of 20-40 cm, a plow sole is formed, the density of which reaches 1.40-1.50 g/cm3. When loosening the soil with CP-2.5, the plow sole was destroyed, but subsoil ridges remained in the inter-tracks of the working organs, which did not collapse during the winter and spring periods. To eliminate subsoil ridges and plow soles, the chisel ripper CR-2.4 was developed, which provides: continuous loosening of the soil to a depth of 35 cm. In the process of setting up field experiments, the influence of the methods of main tillage on its agro- and water-physical indicators was determined. The soil's best agro- and water-physical properties are provided by the option with autumn loosening of the soil to a depth of 35 cm with the chisel ripper CR-2.4. On this option, the amount of total and available moisture when sowing corn was 20 and 16.7%, respectively, and when harvesting by 18.5 and 17.0%. Higher than on the option with moldboard plowing. Differences in soil density and levels of moisture stored in it influenced the development of corn plants and their yield. On the variants with deep chisel tillage, the accumulation of dry and raw plant biomass and the yield of corn grain were higher.

On average, over two years, the dry weight of ten plants in the phase of full ripeness after autumn plowing SRP-4-40 was 1376 g, for CP-4.5 - 1491 g, for CR-2.4 - 1532 g. The increase in the grain yield of corn according to the option with soil chiseling CP-4, in comparison with plowing, on average for two years amounted to 7.2 dt/ha; according to the option with chiseling CR-2.4-17.1 dt/ha.

Thus, the methods of main tillage allow regulating the agro- and water-physical state of the soil and have a significant impact on the productivity of corn. The most promising method of tillage is its continuous chisel loosening to a depth of 35 cm without leaving subsoil ridges.

References

Abdullah, A. (2019). Identifying agriculture land acquisitions for alleviating future food security concerns. *Food Science and Technology*, 39(2), 301-307. http://dx.doi.org/10.1590/fst.24917.

Burtseva, N. I., Dronova, T. N., & Golovatyuk, O. V. (2021). Revisited the matter of the fodder galega new feed crop cultivation on the irrigated lands of the Lower Volga region. In K. E. Tokarev (Eds.), *IOP Conference Series: Earth and Environmental Science - Mathematical Modeling of Technical and Economic Systems in Agriculture III* (Vol. 786, pp. 012003). Bristol: IOP Publishing Ltd.

Chen, T., & Yu, S. (2021). Research on food safety sampling inspection system based on deep learning. *Food Science and Technology*. http://dx.doi.org/10.1590/fst.29121.

Darko, R. O., Liu, J., Yuan, S., Sam-Amoah, L. K., & Yan, H. (2020). Irrigated agriculture for food self-sufficiency in the sub-Saharan African region. *International Journal of Agricultural and Biological Engineering*, 13(3), 1-12. http://dx.doi.org/10.25165/j.ijabe.20201303.4397.

Hecht, A. A., Biehl, E., Barnett, D. J., & Neff, R. A. (2019). Urban food supply chain resilience for crises threatening food security: a qualitative study. *Journal of the Academy of Nutrition and Dietetics*, 119(2), 211-224. http://dx.doi.org/10.1016/j.jand.2018.09.001. PMid:30527912.

Hendrickson, M. K. (2015). Resilience in a concentrated and consolidated food system. *Journal of Environmental Studies and Sciences*, 5(3), 418-431. http://dx.doi.org/10.1007/s13412-015-0292-2.

Karavani, A., Cáceres, M., Aragón, J. M., Bonet, J. A., & de-Miguel, S. (2018). Effect of climatic and soil moisture conditions on mushroom productivity and related ecosystem services in Mediterranean pine stands facing climate change. *Agricultural and Forest Meteorology*, 248, 432-440. http://dx.doi.org/10.1016/j.agrformet.2017.10.024.

Ker, A. P. (2020). Risk management in Canada's agricultural sector in light of COVID-19. *Canadian Journal of Agricultural Economics*, 68(2), 251-258. http://dx.doi.org/10.1111/cjag.12232.

Łabędzki, L. (2016). Actions and measures for mitigation drought and water scarcity in agriculture. *Journal of Water and Land Development*, 29(1), 3-10. http://dx.doi.org/10.1515/jwld-2016-0007.

Lima, C. Z., Buzan, J. R., Moore, F. C., Baldos, U. L. C., Huber, M., & Hertel, T. W. (2021). Heat stress on agricultural workers exacerbates crop impacts of climate change. *Environmental Research Letters*, 16(4), 044020. http://dx.doi.org/10.1088/1748-9326/abeb9f.

Mesterházy, Á., Oláh, J., & Popp, J. (2020). Losses in the grain supply chain: causes and solutions. *Sustainability*, 12(6), 2342. http://dx.doi.org/10.3390/su12062342.

Nakat, Z., & Bou-Mitri, C. (2021). COVID-19 and the food industry: readiness assessment. *Food Control*, 121, 107661. http://dx.doi.org/10.1016/j.foodcont.2020.107661. PMid:33013004.

Pismennaya, E. V., Azarova, M. Y., Stukalo, V. A., & Perederieva, V. M. (2020). Influence of technology without tillage on indicators of soil fertility in arid conditions of the South of Russia. In I. V. Kovalev, N. I. Pyzhikova, Z. E. Shaporova & A. A. Voroshilova (Eds.), *IOP Conference Series: Earth and Environmental Science- III International Conference on Agribusiness, Environmental Engineering and Biotechnologies – AGRITECH-III* (Vol. 548, pp. 022020). Bristol: IOP Publishing Ltd. http://dx.doi.org/10.1088/1755-1315/548/2/022020.

Rai, R. (2020). Heat stress in crops: driver of climate change impacting global food supply. In P. Singh, R. P. Singh & V. Srivastava (Eds.), *Contemporary environmental issues and challenges in era of climate change* (pp. 99-117). Singapore: Springer. http://dx.doi.org/10.1007/978-981-32-9595-7_5.

Riaz, F., Riaz, M., Arif, M. S., Yasmeen, T., Ashraf, M. A., Adil, M., Ali, S., Mahmood, R., Rizwan, M., & Hussain, Q. (2020). Alternative and non-conventional soil and crop management strategies for increasing water use efficiency. In S. Fahad, M. Hasanuzzaman, M. Alam, H. Ullah, M. Saeed, I. A. Khan & M. Adnan (Eds.), *Environment, climate, plant and vegetation growth* (pp. 323-338). Cham: Springer.

Rigden, A. J., Mueller, N. D., Holbrook, N. M., Pillai, N., & Huybers, P. (2020). Combined influence of soil moisture and atmospheric evaporative demand is important for accurately predicting US maize yields. *Nature Food*, 1(2), 127-133. http://dx.doi.org/10.1038/s43016-020-0028-7.

Salama, H. S., Nawar, A. I., Khalil, H. E., & Shaalan, A. M. (2021). Improvement of maize productivity and N use efficiency in a no-tillage irrigated farming system: effect of cropping sequence and fertilization management. *Plants*, 10(7), 1459. http://dx.doi.org/10.3390/plants10071459. PMid:34371662.

Sattar, A., Sher, A., Ijaz, M., Ul-Allah, S., Rizwan, M. S., Hussain, M., Jabran, K., & Cheema, M. A. (2020). Terminal drought and heat stress alter physiological and biochemical attributes in flag leaf of bread wheat. *PLoS One*, 15(5), e0232974. http://dx.doi.org/10.1371/journal.pone.0232974. PMid:32401803.

Singh, A., Kumari, S., Malekpoor, H., & Mishra, N. (2018). Big data cloud computing framework for low carbon supplier selection in the beef supply chain. *Journal of Cleaner Production*, 202, 139-149. http://dx.doi.org/10.1016/j.jclepro.2018.07.236.

Suleimenova, N., Orynbasarova, G., Suleimenova, M., Bozhbanov, A., & Yerekeyeva, S. (2021). Environmental monitoring of the sustainability and productivity of the agroecosystem of oilseeds in South-East Kazakhstan. *Journal of Ecological Engineering*, 22(7), 89-99. http://dx.doi.org/10.12911/22998993/139114.

Wang, X., Qi, J., Liu, B., Kan, Z., Zhao, X., Xiao, X., & Zhang, H. (2020). Strategic tillage effects on soil properties and agricultural productivity in the paddies of Southern China. *Land Degradation & Development*, 31(10), 1277-1286. http://dx.doi.org/10.1002/ldr.3519.

Yadav, G. S., Lal, R., Meena, R. S., Babu, S., Das, A., Bhowmik, S. N., Datta, M., Layak, J., & Saha, P. (2019). Conservation tillage and nutrient management effects on productivity and soil carbon sequestration under double cropping of rice in north eastern region of India. *Ecological Indicators*, 105, 303-315. http://dx.doi.org/10.1016/j.ecolind.2017.08.071.

Zakharov, V. L., & Morgacheva, N. V. (2020). Comparison of water-physical and microbiological properties of apple orchards soils with indicators in other agricultural lands. In I. V. Kovalev, N. I. Pyzhikova & A. A. Voroshilova (Eds.), *IOP Conference Series: Earth and Environmental Science - II International Conference on Agribusiness, Environmental Engineering and Biotechnologies - AGRITECH-II* (Vol. 421, pp. 022011). Bristol: IOP Publishing Ltd. http://dx.doi.org/10.1088/1755-1315/421/2/022011.

Zulfiqar, U., Hussain, S., Ishfaq, M., Matloob, A., Ali, N., Ahmad, M., Alyemeni, M. N., & Ahmad, P. (2020). Zinc-induced effects on productivity, zinc use efficiency, and grain biofortification of bread wheat under different tillage permutations. *Agronomy*, 10(10), 1566. http://dx.doi.org/10.3390/agronomy10101566.