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Influence of Soil Tillage and the Preceding Crop on Certain Indicators of Soil Fertility and Yield of Spring Wheat under the Conditions of the Dry Steppe of North Kazakhstan

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ABSTRACT

The main factor limiting crop productivity in arid conditions is the deficiency of atmospheric and soil moisture. Soil cultivation in dry land farming is used as a regulator of accumulation and conservation of soil moisture. In this regard, in 2010-2016, in the conditions of the arid steppe of Northern Kazakhstan ($50^0 64^/$N; $71^0 02^/$E), research was carried out to study the long-term use of tillage technologies in the cultivation of spring wheat (*Triticum aestivum L.*). In the experiment, the researchers studied the influence of traditional deep dry land ploughing (DDLP), shallow dry land ploughing (SDLP), paraploughing (PP) and no-till cultivation (NT) on the dynamics of productive moisture reserves, structural condition, density and filtration capacity of the soil, as well as spring wheat productivity. Studies have shown that a decrease in the intensity of soil cultivation leads to a compaction of the arable layer, reaching maximum values in the no-till system. With an increase in density, the filtration capacity of the soil proportionally decreases, which negatively affects the level of moisture reserves for sowing and ultimately affects the yield of spring wheat. It is shown that in the conditions of an arid steppe, the best option, ensuring the accumulation of soil moisture and a favorable physical condition of the soils, is deep fall tillage, while a greater positive effect is achieved in case of the non-fallow preceding crop. Wheat yields, in case of fallow wheat, do not depend on tillage.

KEYWORDS

Soil Tillage, Preceding Crop, Spring Wheat, Soil Properties, Productivity.

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Introduction

Soil tillage in the agricultural system is considered as a powerful factor in influencing soil conditions and properties, at the same time solving the problems of decompaction of the arable layer and weed control (Alarcón, 2018; Hosseini, 2016; Alam, 2014). The focus of modern production on resource conservation and eco-friendliness reduces the role of tillage as a regulator of soil fertility. In part, the functions of soil tillage are solved by correct crop rotation, as well as by expanding the range of crops in the structure of field cultivation (diversification) (Busari, 2015; Büchi, 2018).

The natural conditions of Northern Kazakhstan are characterized by a sharp continental climate, a large amplitude of fluctuations in air temperature, prolonged and low snowy winters, low relative humidity and a small amount of precipitation. The average annual rainfall is 319 mm, of which 134.7 mm falls during the growing season (June - August). The combination of high temperatures with strong wind and rapidly occurring dryness in the first half of summer makes plant development more dependent on moisture reserves in the soil accumulated before sowing. For a long time in the arid regions of Northern Kazakhstan and Western Siberia, the classical technology of tillage based on deep dry land ploughing (DDLP) was applied. Also, in order to increase productivity and reduce costs, the applied technologies were based on minimal influence on the soil by reducing the depth and frequency of tillage (Suleimenov, 2016; Vlasenko, 2003; Kholmov, 2006; Baraev, 1978). The possibility of minimizing soil cultivation or a complete transition to the no-till method depended on the cultivation zone, the type of soil, its mechanical and mineralogical composition, as well as the tendency to re-compaction, since for each crop there is an optimal range of parameters beyond which their productivity decreases sharply (Khurshid, 2006; Derpsch, 2010). Therefore, for cost-effective farming, it is necessary to make the right choice of cultivation technology with an appropriate farming system and crop rotation (Yang, 2017; Zabolotskikh, 2019).

In this regard, in the conditions of an arid steppe, on the territory of the "Scientific-production center of grain farm named after A.I. Barayev" ($50^0 64^/$N; $71^0 02^/$E), for seven years, the long-term use of various tillage technologies for spring wheat cultivation has been studied in a five-course grain rotation (fallow - wheat - wheat - rapeseed - wheat) and crop rotation (pea - wheat - wheat - rapeseed - wheat) farming.

Research Methodology

In 2010-2016, on the basis of stationary field experiment of precision farming laboratory, the influence of soil cultivation techniques on the dynamics of productive moisture reserves in the 1-meter thick layer, the structure, density and filtration capacity of the 30 cm arable layer, the yield of spring wheat in the fallow grain and crop rotation was studied. The soil of the research area is represented by southern carbonate heavy loamy chernozem with a humus content of 3.2%; gross nitrogen - 0.2%; phosphorus - 0.1%. In the soil under consideration, potassium is the predominant mobile nutrient, the content of which in the arable layer ranges from 82 to 116 mg/100 g of soil; the reaction of the soil solution is slightly alkaline - pH 7.3.

The zonal farming system excludes tillage techniques with a turnover of the soil and strong grinding of the surface layer. The systematic use of deep ploughing and cultivation with a disk harrow at the early stages of the establishment of the farming system in the research zone led to the development of erosion processes, the loss of the fertile layer and reduced soil productivity. In this regard, the following options were introduced: deep dry land ploughing

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(DDLP-I) using a ПГ-3-5 subsurface cultivator to a depth of 25-27 cm; shallow dry land ploughing (SDLP-II) with a КПШ-9 wide-angle subsurface cultivator to a depth of 10-12 cm; paraploughing (PP-III) with a ЩР-4,5 paraplough to a depth of 25-27 cm with a 0.7 m distance between chisel racks, and the no-till option introduced into the stationary field experiment since 2004. The working parts of tillage tools are shown in Figure 1.

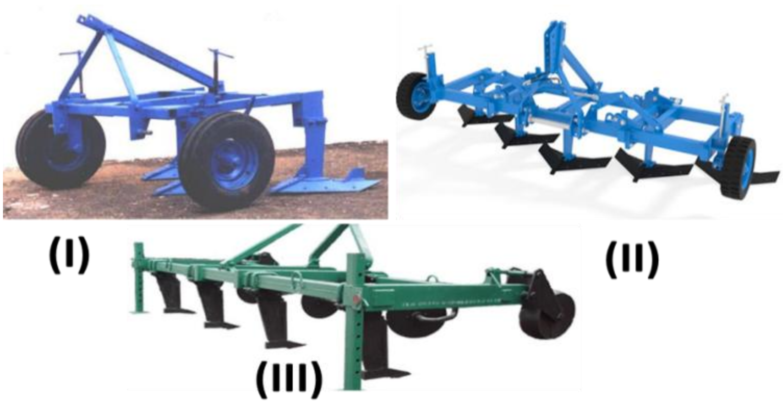

Fig. 1. Working parts of tillage tools

In the experiment, the land plots were located in randomized blocks; the observations in the experiment were carried out in triplicate. The plot area was 1776 m^2, the harvested crops were registered by a combine, with an area of 500 m^2, with a result of 14% humidity and 100% purity. Mineral fertilizers were not used in the experiment, so as not to neutralize the influence of the factors of soil tillage and preceding crops. In the experiments, spring soft wheat of the midseason-ripening group - Akmola 2 was sown; the vegetation period of this variety is 85-90 days. In spring, in case of DDLP, SDLP and PP variants, harrowing was carried out with a rotary soil spiker (БИГ-3А); sowing was carried out using a sowing-machine with cultivator type plowshares. The agricultural practice used in the experiment is typical for the studied area; sowing was carried out in the second decade of May, with a sowing rate of 2.5-2.7 million germinating seeds per 1 hectare. On the no-till option, in the pre-sowing period, glyphosate-containing herbicides were sprayed on the territory (1.5-2.0 l/ha); sowing was carried out with a direct seeding sowing-machine with a chisel plowshare. During the growing season, a comprehensive chemical protection of plants against weeds, diseases and insects was carried out. Harvesting was carried out by direct combining, with grinding and scattering of plant residues. All observations were carried out according to the generally accepted methods of field and laboratory studies. The content of productive moisture was determined thermostatically by the weight method in layers, with a 0.1 m spacing to a depth of 1 m (Bakaev, 1975). The content of soil aggregates was determined by the method of fractionation of dry soil on sieve columns with a diameter of 10; 7; 5; 3; 2; 1; 0.5 and 0.25 mm. Aggregates ranging in size from 0.25 to 10 mm are considered to be agronomically valuable. Aggregates of >10 mm are referred to a cobble fraction, < 0.25 mm to a dust fraction (Revuta, 1969). Soil density was determined by the cutting ring method using standard metal cylinders with a volume of 500 cm^3; the filtration capacity was measured on a filtration unit, maintaining a constant water layer on the surface in soil samples of undisturbed composition after six hours of observation, when the soil swelled and the filtration processes stabilized (Vadyunina, 1986).

The research region belongs to the risky farming zone and is characterized by significant fluctuations in both atmospheric precipitation and temperature indicators. The amount of precipitation in the research region is almost four times less than evaporation, which indicates

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a strong aridity of the climate. The water regime belongs to the non-irrigation type, groundwater is located at great depths - more than 10 m. The only reserve of soil moisture is winter rainfall, absorbed by the soil when snow melts. In spring, the soil is soaked only at a shallow depth of 0.5-2.0 m. Under the moistened layer a stable humidity is maintained, which is close to the wilting moisture of plants. The research period covered the whole variety of meteorological conditions and their impacts on the yield of the studied culture. The characteristics of the main meteorological indicators of the research period are presented in Table 1.

Table 1. Meteorological characteristics of the 2010-2016 research period

Agricultural year (September-August)	Amount of precipitation per year, mm	Amount of precipitation during the growing season*, mm	Average temperature during the growing season, t^0C	Sum of temperatures>0^0C	HTC** during the growing season
2009-2010	198.7	49.0	20.4	1861	0.3
2010-2011	300.0	162.3	18.6	1697	1.0
2011-2012	207.1	100.7	20.5	1875	0.5
2012-2013	398.7	139.8	19.2	1813	0.8
2013-2014	427.4	148.0	19.9	1797	0.8
2014-2015	415.9	156.1	19.4	1762	0.9
2015-2016	326.3	156.0	17.6	1600	1.0
Long-time annual average indicators***	319.4	134.7	18.5	1691	0.8
Note: * precipitation in June, July, August ** hydrothermal coefficient according to G.T. Selyaninov *** average data for 1936-2016					

The analysis of meteorological conditions shows that during the research period, two years were acutely arid, with increased heat supply, three years were close to long-term average values, and two were quite humid, with a low temperature background. Such fluctuations caused changes in soil fertility and productivity of spring wheat in the context of the studied tillage options.

Results and Discussion

The main limiting factor in the conditions of an arid steppe is moisture availability, therefore, all elements of the agriculture technology should be aimed at the maximum possible conservation and rational use of soil moisture by plants (Zabolotskikh, 2015; Hemmat, 2004). The results of observations of the productive moisture content accumulated before wheat sowing showed that, regardless of the conditions of the year, the moisture supply for the preceding fallow crop was significantly higher (Table 2). The maximum moisture reserves were formed under conditions of deep dry land ploughing and paraploughing. On average over seven years, the moisture content of these options was in the range of 115.6 - 112.6 mm after fallow crops and 108.5 - 105.4 mm after peas. It should also be noted that, in case of the no-till option, the difference between the preceding fallow crop and peas was more than 20 mm, while in the options with mechanical tillage it did not exceed 7-9 mm. The differences

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were especially noticeable in the extremely arid 2010 and 2012, when the shortfall of precipitation was 38 and 35%, respectively.

Table 2. Productive moisture content in a 1-meter layer (mm) accumulated before sowing spring wheat, depending on the method of soil tillage and the preceding crop

Soil cultivation method	Preceding crop	Years							Average
		2010	2011	2012	2013	2014	2015	2016	
ПГ-3-5 subsurface cultivator; depth: 25-27 cm	Fallow crop	99.5	115.1	79.1	119.5	123.2	151.0	121.4	115.5
	Peas	99.1	113.5	69.7	116.7	121.4	139.0	100.1	108.5
КПШ-9 wide-angle subsurface cultivator; depth: 10-12 cm	Fallow crop	94.4	101.1	78.0	105.0	107.4	134.8	112.3	104.7
	Peas	86.2	89.3	65.3	104.6	100.4	130.7	93.4	95.7
ЩР-4,5 paraplough; depth: 25-27 cm	Fallow crop	97.3	113.8	84.2	109.9	121.8	142.2	118.7	112.6
	Peas	95.8	111.4	68.6	110.1	114.7	138.3	99.2	105.4
No-till method	Fallow crop	97.2	115.7	104.1	105.3	100.9	120.0	116.0	108.5
	Peas	62.8	84.1	70.2	86.2	78.3	91.7	89.7	80.4
Least significant difference for 5% level (LSD_{05})		by factor "A" (soil cultivation)							6.5
		by factor "B" (preceding crop)							4.6
		"AB" (for average ratios)							9.2

The moisture level of the soil is largely determined by the state of the agrophysical indicators of the arable layer and, first of all, by the density and filtration capacity of the soil (Feng, 2018; Feki, 2018). Therefore, observations of density and filtration capacity in the study of tillage techniques are of particular importance. It has been proved that the density and filtration capacity of the soil is a function of the structure and microstructure, which depends on the ratio of aggregates of different sizes, particle size distribution, organic matter content, moisture state and can change depending on the intensity of mechanical tillage (Ma, 2016). Observations of soil density have shown the dependence of this indicator on the tillage technique. It has been noted that a decrease in the intensity of impact on the soil leads to a significant compaction of the arable layer. The use of reasonable cultivation systems stabilizes the physical state of the soil and prevents it from going beyond critical limits (Jabro, 2010; Agostini, 2012; Khan, 2017; He, 2012). In case of the no-till method - a no-till option up to the values of its equilibrium state - 1.3 g/cm^3 (Table 3). According to the results of the experiment, no significant effect of the studied preceding crops on the state of compaction of the arable layer has been revealed. The change in this indicator occurred under the influence of meteorological conditions of individual years, with a common trend for all studied options. Structurally, the most loose (1.23 - 1.24 g/cm^3), irrespective of the conditions of the year, was the variant of deep dry land ploughing, since the intensive impact of the subsurface cultivator in the horizontal and vertical directions contributed to a uniform decompaction of the entire cultivated layer. The density of the soil in the options for shallow dry land ploughing and paraploughing for an average of 7 years amounted to 1.26 g/cm^3, however, the mechanism for

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the formation of this indicator between the options is fundamentally different. Thus, in the variant of shallow dry land ploughing, a layer of 0-10 cm is subject to intensive tillage, the soil density of the arable horizons increases sharply. In case of paraploughing, volumetric deformations and decompaction of a layer of up to 30 cm occur in places of paraploghing, and the spaces between the furrows are not processed, therefore, the soil density of these areas practically does not change.

Table 3. Density of the arable layer (0-30 cm) accumulated before sowing spring wheat, depending on the method of soil tillage and the preceding crop

Soil cultivation method	Preceding crop	Soil density, g/cm^3							Average
		2010	2011	2012	2013	2014	2015	2016	
ПГ-3-5 subsurface cultivator; depth: 25-27 cm	Fallow crop	1.18	1.16	1.22	1.29	1.23	1.27	1.27	1.23
	Peas	1.21	1.20	1.27	1.27	1.23	1.30	1.20	1.24
КПШ-9 wide-angle subsurface cultivator; depth: 10-12 cm	Fallow crop	1.21	1.18	1.27	1.26	1.27	1.33	1.30	1.26
	Peas	1.24	1.23	1.28	1.30	1.23	1.33	1.21	1.26
ЩР-4,5 paraplough; depth: 25-27 cm	Fallow crop	1.23	1.25	1.25	1.27	1.25	1.33	1.26	1.26
	Peas	1.24	1.25	1.27	1.28	1.24	1.31	1.21	1.26
No-till method	Fallow crop	1.28	1.31	1.31	1.33	1.27	1.33	1.32	1.31
	Peas	1.29	1.30	1.31	1.34	1.27	1.34	1.29	1.31
Least significant difference for 5% level (LSD_{05})		by factor “A” (soil cultivation)							0.019
		by factor “B” (preceding crop)							0.013
		“AB” (for average ratios)							0.026

These differences are confirmed by the data on the content of productive moisture accumulated before sowing (Table 2), where the moisture indicators in the paraploughing background were significantly higher than the option with shallow dry land ploughing. In addition, the state of the background and the amount of plant residues on the surface had an effect on the soil moisture reserve in the studied options (Brunel-Saldias, 2016). The soil surface in the no-till options, having no stubble cover after harvesting peas, had no preconditions for the accumulation of snow, as a result of which a moisture deficit, including the moisture consumed by the preceding crop, was not restored before sowing wheat.

A long non-cultivation period and the use of the no-till option in the experiment formed the density of the arable layer at the level of 1.31 g/cm^3, regardless of the preceding crop. The absence of sharp fluctuations and more stable density indices for this option should also be noted under the conditions of years with different moisture availability, in comparison with options involving mechanical tillage.

A change in the density of structure directly affects the filtration capacity of the soil (Feng, 2018), on which in arid conditions the level of soil moisture reserve depends (Feki, 2018). Studies have shown that the filtration capacity of the arable layer has an inverse dependence on soil density, and also varies significantly depending on tillage methods (Table 4). An analysis of the data has shown that the best indicators of filtration capacity are characteristic

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for the soil in case of deep ploughing - 0.62-0.50 and paraploughing - 0.50-0.41 mm/min. Against the background of shallow dry land ploughing, the indicator decreased by 0.15-0.05 mm/min. In no-till options, water filtration did not exceed 0.25-0.22 mm/min, and did not depend on the preceding crop.

Table 4. Filtration capacity of the arable layer (0-30 cm) before sowing spring wheat, depending on the method of soil tillage and the preceding crop

Soil cultivation method	Preceding crop	Filtration capacity, mm/min, 6th hour							Average
		2010	2011	2012	2013	2014	2015	2016	
ПГ-3-5 subsurface cultivator; depth: 25-27 cm	Fallow crop	0.38	1.03	0.53	0.82	0.52	0.56	0.49	0.62
	Peas	0.29	1.17	0.43	0.48	0.33	0.31	0.51	0.50
КПШ-9 wide-angle subsurface cultivator; depth: 10-12 cm	Fallow crop	0.31	0.78	0.38	0.60	0.45	0.31	0.36	0.46
	Peas	0.24	0.82	0.30	0.24	0.24	0.29	0.36	0.36
ЩР-4,5 paraplough; depth: 25-27 cm	Fallow crop	0.42	0.77	0.51	0.76	0.48	0.34	0.22	0.50
	Peas	0.30	0.93	0.38	0.32	0.36	0.33	0.25	0.41
No-till method	Fallow crop	0.19	0.36	0.19	0.43	0.31	0.16	0.12	0.25
	Peas	0.20	0.33	0.21	0.20	0.31	0.19	0.09	0.22
Least significant difference for 5% level (LSD_{05})		by factor “A” (soil cultivation)							0.09
		by factor “B” (preceding crop)							0.06
		“AB” (for average ratios)							0.129

It should also be noted that there is a tendency for the soil filtration capacity to increase in the spring after severely arid years of 2010 and 2012, when the residual moisture reserves were close to the wilting moisture of plants. Under such conditions, when the arable horizon is drained and the soil is compacted to the state of “ultimate shrinkage”, the soil surface is covered with a thick network of cracks of various lengths and depths, which explains the increase in filtration capacity (Zabolotskikh, 2012; Tang, 2016).

The relationship of density and filtration capacity of the arable layer described above can be expressed by the regression equation. The interconnection of these indicators largely determines the level of productive moisture reserves accumulated before sowing, which is one of the main factors of crop productivity in conditions of precipitation deficiency. The linear regression equation for soil density and filtration capacity is shown in Figure 2.

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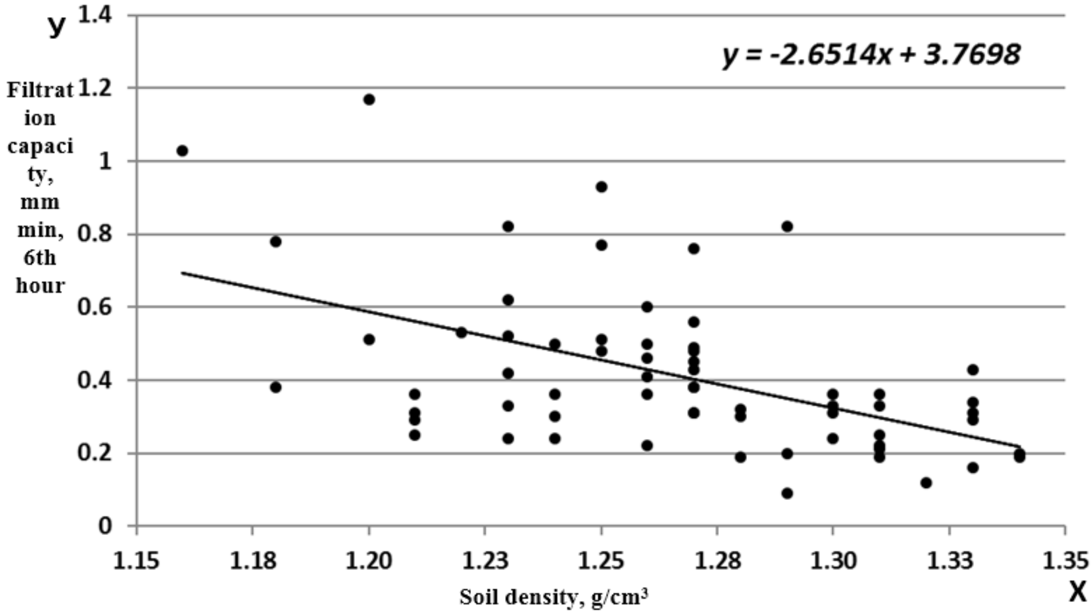

Fig. 2. Linear regression equation for soil density and filtration capacity indicators

One of the important agrophysical indicators of the arable layer that affects soil fertility is its structure, which can be characterized by the number of agronomically valuable aggregates varying from 0.25 to 10 mm. Mechanical tillage directly influences the formation of the soil structure through crumbling, loosening and mixing of the soil aggregates, regulating water, air and thermal conditions (Pagliai, 2004).

Studies have shown that the systematic use of mechanical tillage helps to stabilize the soil structure (Jabro, 2010; Agostini, 2012; Khan, 2017). On average, over 7 years of observation, the number of valuable aggregates in options with mechanical tillage varied within the range of 70.9-75.6%, while in the absence of tillage this indicator decreased to 64.5-61.5%, which is primarily due to soil compaction and an increase of >10 mm clumpy fraction content (Table 5). Possibly, a degradation of the quality of the soil structure is due to the low intake of organic matter in the form of plant residues, since in case of a long no-till period, the processes of transformation of plant residues occur on the soil surface and do not affect the deeper layers of the soil. The shown comparative analysis of the content of agronomically valuable aggregates in case of application of the studied soil cultivation technologies has a conventional character, since changes in the structural state of the soil in the studied variants occurred within the same gradation and according to the scale for assessing the soil structure by S.I. Dolgova and P.U. Bakhtina belonged to the category of “good” (Vadyunina, 1986).

Table 5. Content of agronomically valuable aggregates (10-0.25 mm) in a 0-10 cm layer before sowing spring wheat, depending on the method of soil tillage and the preceding crop

Soil cultivation method	Preceding crop	Content of agronomically valuable aggregates,%							Average
		2010	2011	2012	2013	2014	2015	2016	
ПГ-3-5 subsurface cultivator; depth: 25-27 cm	Fallow crop	58.1	83.8	74.5	77.0	76.9	81.2	78.0	75.6
	Peas	45.3	79.1	72.4	71.7	76	75.9	77.8	71.2
КПШ-9 wide-angle subsurface cultivator; depth:	Fallow crop	35.8	80.0	69.7	79.0	75.7	80.6	78.6	71.3
	Peas	37.3	82.7	77.9	78.4	76.7	79.4	79.3	73.1

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10-12 cm									
ЩР-4,5 paraplough; depth: 25-27 cm	Fallow crop	57.3	81.4	75.2	81.0	76.1	72.4	79.4	74.7
	Peas	48.3	80.4	69.0	68.3	72.9	80.3	76.8	70.9
No-till method	Fallow crop	38.1	68.0	69.6	56.9	74.0	71.0	74.2	64.5
	Peas	34.3	76.1	60.4	53.4	68.4	66.2	71.9	61.5
Least significant difference for 5% level (LSD_{05})		by factor “A” (soil cultivation)							3.6
		by factor “B” (preceding crop)							3.5
		“AB” (for average ratios)							5.1

Of particular importance in the formation of the soil structure are the meteorological conditions of the spring period. Thus, after a snowy winter and a dry spring period of 2010, with a low soil moisture content accumulated before sowing, a decrease in the quality of the soil structure was noted, regardless of the cultivation technology. Drying and compaction of the soil contributed to the formation of aggregates of clumpy fraction, and with the destruction of blocks to the formation of a dusty fraction; the content of valuable aggregates did not exceed 34.3-58.1%. The positive effect of the preceding fallow crop on the content of valuable aggregates in the soil was noted in the background of deep dry land ploughing; in other options, the differences were unreliable.

A general indicator of the assessment of soil cultivation technologies is productivity. The yield of spring wheat during the research period was highly dependent on the agrometeorological conditions of individual years (Kholmov, 2006; Meng, 2017; Urban, 2012; Sdobnikov, 1964; Sharkov, 2016), as evidenced by the high coefficient of variation over the years (CV = 55%). On average over 7 years, the yield of the first wheat sown after the preceding fallow crop varied within the range of 17.0-18.2 hundred kilos per hectare and did not significantly differ between tillage options (Table 6).

Table 6. Yields of the 1st and 2nd wheat, depending on the tillage technology and the preceding crop (2010-2016)

Soil cultivation method	Preceding crop	Productivity, hundred kilos per hectare			Aftereffect of the preceding crop in the second culture +/- in relation to the first
		1st wheat	2nd wheat	Averag e	
ПГ-3-5 subsurface cultivator; depth: 25-27 cm	Fallow crop	17.7	16.8	17.3	- 0.9
	Peas	16.4	17.6	17.0	+ 1.2
КПШ-9 wide-angle subsurface cultivator; depth: 10-12 cm	Fallow crop	17.0	16.3	16.7	- 0.7
	Peas	15.8	16.8	16.3	+ 1
ЩР-4,5 paraplough; depth: 25-27 cm	Fallow crop	17.5	17.4	17.5	- 0.1
	Peas	16.7	16.7	16.7	0
No-till method	Fallow crop	18.2	15.8	17.0	- 2.4
	Peas	15.5	15.7	15.6	+ 0.2

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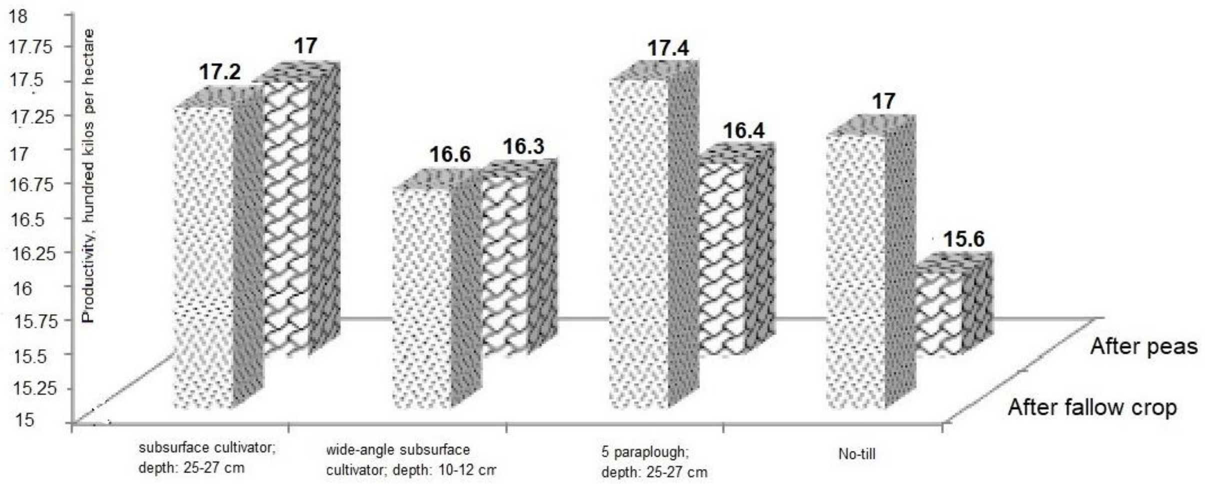
Least significant difference for 5% level (LSD_{05}) for the 1st wheat	by factor “A” (soil cultivation)			1.4
	by factor “B” (preceding crop)			1.0
Least significant difference for 5% level (LSD_{05}) for the 2nd wheat	by factor “A” (soil cultivation)			1.1
	by factor “B” (preceding crop)			1.0
Correlation between productivity and soil moisture before sowing (r =)	0.82	0.55	0.97	-

In case of the second culture, differences were observed in the aftereffect of the studied fallow preparation technologies. If in the variants with mechanical tillage the decrease in yield in the second crop did not exceed 1 hundred kilos per hectare, then in the no-till variant it amounted to 2.4 hundred kilos per hectare. Partly, the low efficiency of the aftereffect is due to the deterioration of the agrophysical indices described above, and the possibly related conditions for the decomposition of plant residues and mineral nutrition.

The productivity of wheat sown after peas in the dry land ploughing and no-till options compared to the preceding fallow crop was 1.2–2.7 hundred kilos per hectare lower, which was confirmed by statistical analysis. The differences between the preceding crops in the paraploughing background were within the tolerance limits. It should also be noted that in years with sufficient moisture supply in the growing season, the positive aftereffect of peas as a preceding crop manifested itself in the second year, although only as a trend. On average, over 7 years, the yield of second wheat sown after peas was 1.2-0.2 hundred kilos per hectare higher than the second crop sown after the fallow crop. This trend can be explained by the low rate of decomposition of pea plant residues in the conditions of an arid steppe, as a result of which nutrients are absorbed only in the second year (Sierra, 2015).

Of particular interest is the analysis of the average yield of the first and second wheat depending on the studied preceding crops (Figure 3). The results of the studies have shown that in the combination of the grain-fallow crop rotation, the wheat yield for two years does not significantly differ between the options, however, there was a trend that in case of deep dry land ploughing and paraploughing (17.2-17.4 hundred kilos per hectare) the yield was higher.



Least significant difference for 5% level (LSD_{05}) for factor A tillage – 1.0; factor B preceding crop – 0.7
For average ratios – 1.4; S_x – 0.49

Fig. 3. Yield of spring wheat depending on the type of tillage and the preceding crop, 2010-2016

A similar tendency remained in the case of crop rotation with peas, however, the minimum yield for two years (15.6 hundred kilos per hectare) was in the no-till option, which turned out to be significantly lower than in case of deep dry land ploughing. An analysis of the data in the context of the preceding crop showed a significant decrease in the yield of wheat sown after peas in case of paraploughing and no-till method. The dry land ploughing options had no differences in terms of their preceding crops.

The described trend in yield changes has a stable relationship with the content of productive moisture accumulated before sowing. The close correlation ($r = 0.97$) between these indicators in the period of research shows the high importance of soil moisture in crop formation, especially in the conditions of an arid steppe.

Conclusion

In the conditions of an arid steppe, the best option, ensuring the accumulation of soil moisture and a favorable physical condition of the soils, is deep fall tillage, while a greater positive effect is achieved in case of the non-fallow preceding crop.

A decrease in the intensity of soil cultivation leads to a compaction of the arable layer reaching maximum values in the no-till system. With an increase in density, the filtration capacity of the soil proportionally decreases, which negatively affects the level of moisture reserves for sowing and ultimately affects the yield of spring wheat. Despite the identified trends, during the period of research in all the studied tillage options, soil density did not exceed the critical limits.

The yield of spring wheat sown after the preceding fallow crop did not depend on the variant of soil tillage and amounted to 17.0–18.2 hundred kilos per hectare. Compared to fallow crop, wheat cultivation after peas reduced grain yield in all tillage options by 1.2–2.7 hundred kilos per hectare. In grain-fallow crop rotation system in case of using mechanical tillage, differences in yield between the first and second crops were not observed.

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