Fall tillage of eroded sod-podzolic soil

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***Abstract*—Implementation of modern technologies for the production of agricultural products in each soil and climatic zone which are based on efficient resource-saving methods of tillage will make a significant contribution to the Federal Scientific and Technical Program for the Development of Agriculture of the Russian Federation. The Cis-Ural region is a large industrial center with well-developed agricultural industry. Sod-podzolic soils predominantly spread on this territory are character-ized by erosional features, low-humusness and weak aggregate strength but with good water provision during growth period one can get good levels of crop yields. Results of this study showed that the various methods of fall tillage of sod-podzolic soil actually do not change its agrophysical properties during the subsequent growth season, the yield of spring wheat and weed infestation of its crops. Therefore, it is economically reasonable to use minimal tillage for growing spring wheat.**

***Keywords*—tillage, yield, spring wheat, agrophysical properties of the soil, weeds.**

I. Introduction

The state of crop production in the Russian Federation is gradually improving: the average yield of crops and leguminous crops in 2017 reached 29.2 centners per hectare, and gross crop output – 135.5 million tons [1]. Produced grain is sufficient for all basic needs of domestic consumption and dozens million tons are annually exported to many countries of the world. But the demand for grain is constantly growing and there is a need to further increase its production. Natural and climatic conditions and the genetic potential of already existing varieties make it possible to reach a significantly higher yield in comparison with that of today. For this purpose, one uses new reserves for expanding acreage, increasing yields and grain quality. Results of the study showed that such reserves for increasing grain production of winter and spring crops are available in the each region of our country, both in typical grain-producing steppe zone of southern Russia, and in the more northern Nonchernozem belt [2, 3, 4] and in the eastern part country.

Federal Scientific and Technical Program for the Development of Agriculture gives the task for the short-term –implementation of modern technologies for the production of agricultural products, raw materials and foodstuffs. The technology of crop growing involves the use of a scientifically based set of technologies that make it possible realize the genetic potential of modern varieties to the full extent and that are most adapted to the maximum use of biotic and abiotic factors of specific natural and climatic zone.

Middle Cis-Ural region located in the east of the European part of Russia is characterized by hilliness with well-marked depressions and lowlands. The soil is predominantly low-humus sod-podzolic with a non-water-stable micro- and macrostructure and an equilibrium density of plowing layer of 1.4–1.5 g/cm^3 and of subsurface layer of 1.5–1.7 g/cm^3 what contributes to the development of water erosion which covers 78% of arable land. In addition, this territory is characterized by a short growth season, the sum of temperatures above +10 °C within 1600–2500 °C, and the amount of annual precipitation of 450–550 mm [5, 6].

Tillage system is, as a rule, the most expensive part in the whole complex of technologies used for crop growing. Instead of previously widely used high-cost, low-productive and erosion-dangerous moldboard fall plowing, especially in the zone of soil erosion, boardless subsurface plowing and chisel plowing were offered. The next stage was mastering various options for energy-saving minimal tillage, and more recently – no-till (without tillage) and strip-till (strip tillage) technologies. However, due to the large diversity of the territory of the Russian Federation and different methodological approaches to tillage systems, there is no absolute answer about the advantages of certain basic tillage system [7, 8].

Foreign publications also give various assessments of primary tillage systems. Thus, it was found that moldboard plowing leads to the destruction of soil microaggregates and enhances the loss of carbon dioxide emitted by microbial biomass [9] what is 20% larger than with zero tillage (ZT) [10]. One of the main problems with the refusal of conventional moldboard plowing is increasing the growth of weeds what, without any appropriate additional measures, leads to a decrease in the yield of cultivated plants [11]. Although deep tillage of 30 cm alone, with the same yield as compared with basic surface tillage, was ineffective against perennial weeds [12]. As for evaluation of the economic component of tillage methods, some authors say that minimal and zero tillage providing an average yield increase by 18% give lower average annual net income due to high costs of agricultural equipment and herbicides compared to conventional tillage [13]. Other authors, comparing the minimal tillage, moldboard plowing, deep chisel plowing and mulching, note the absence of any significant differences in the studied parameters including crop yields but low cost value of minimal tillage determines its advantage [14].

The goal of our work was a comparative assessment and identification of optimal methods of fall plowing for spring wheat cultivation..

II. Results

Empirical and theoretical methods were used for this research. The empirical method was presented by threefactor field study (several variants are specified in this article) made in 2013–2015 on sod-medium podzolic middle loamy soil slightly subject to water erosion. Agrochemical characteristics of the soil: humus content – 1.3-2.4%; pH_{KCl} 4.8-5.3; labile phosphorus content – 175-245 mg/kg; exchangeable potassium content – 136-210 mg/kg. Plot tier during the study was fourfold. The previous crop for spring wheat was red clover. All technological operations for spring wheat growing were carried out using industrial equipment and mechanisms in accordance with the regional recommendations.

Meteorological conditions of growth season over the years of research differed significantly but were characteristic for Middle Cis-Ural region. So, in 2013, there was high average daily temperature and precipitation deficit; in 2014, moderate temperature with sufficient precipitation; in 2015, alternating conditions with high average daily temperature and precipitation deficit in the first half of growth period, and subnormal temperature with an precipitation surplus in its second half.

III. DEPENDENCE OF SOIL AGROPHYSICAL PROPERTIES ON ITS TILLAGE

The content of the fraction of particles with a size of 0.25-10 mm in the soil is one of the important agrophysical properties since they in a great measure determine the favorable properties of the soil (Table 1).

TABLE I. THE CONTENT OF SOIL FRACTION OF 0.25-10 MM IN PLOWING LAYER AT THE END OF SPRING WHEAT GROWTH SEASON DEPENDING ON FALL PLOWING METHOD, %

Tillage method	***Year***			***Average***
	2013	***2014***	***2015***	
Moldboard plowing (control)	52.0	57.5	62.6	57.3
Deep chisel plowing	52.6	55.4	57.9	55.3
2-row disk harrow	52.0	56.1	59.7	55.9
Erosion-preventing tillage	62.2	58.6	60.6	60.5
4-row disk harrow	59.2	57.9	59.5	58.9
Average	55.6	57.1	60.1	57.6
LSD_{05}	4.6	4.3	$F_f < F_{05}$	3.4

Results of the study showed that during only one year out of the three, the soil structure was characterized as excellent on average (more than 60%). In other years, this parameter was estimated as good (60–40%). Among the studied variants of fall tillage, only in extremely dry 2013 when during three out of the four months of growth period there was about a half of precipitation norm, after the fall erosion-preventing tillage using KPE-3.8 and four-row disk harrow using KMBD 3×4P, soil structure was significantly better than after moldboard plowing using PLN-5-35. We think that it is due to the fact that after fall plowing during the autumn-winter-spring and summer periods, when the soil is moistened, soil aggregates of low-humus sod-podzolic soil destroy, and there are no differences between the studied methods when spring wheat harvesting period comes.

Another important parameter of soil agrophysical properties is soil density. Here are the following results on this parameter (table 2).

TABLE II. DENSITY OF PLOWING LAYER AT THE END OF SPRING WHEAT GROWTH SEASON DEPENDING ON FALL PLOWING METHOD, G/CM^3

Tillage method	***Year***			***Average***
	2013	***2014***	***2015***	
Moldboard plowing (control)	1.30	1.25	1.27	1.27
Deep chisel plowing	1.30	1.28	1.23	1.27
2-row disk harrow	1.27	1.30	1.31	1.29
Erosion-preventing tillage	1.22	1.32	1.32	1.29
4-row disk harrow	1.27	1.29	1.30	1.29
Average	1.27	1.29	1.29	1.28
LSD_{05}	$F_f < F_{05}$	$F_f < F_{05}$	$F_f < F_{05}$	$F_f < F_{05}$

It was found that during all the years of the study, the average values of soil density approached the upper optimal level (1.1–1.3 g/cm^3). It happened in the case when wheat was planted after red clover which, as is well known, leaves a large number of crop and root residues which improve the agrophysical and agrochemical properties of soil for a long period of time.

None of the growth periods and none of the significantly different methods of fall tillage revealed significant differences in soil density similar to the content of agronomically valuable soil fraction, in comparison to conventional moldboard plowing. We believe that this is also associated with the destruction of soil aggregates and the tendency of the soil to density equilibrium.

IV. DEPENDENCE OF WEED AMOUNT ON TILLAGE

Weed infestation of crops has a direct dependence on soil moistening during growth season. Since the previous crop for spring was red clover, annual, biennial and perennial weeds, and also clover became weeds for this wheat. For an average of three years during tillering stage of spring wheat, the density of these weeds was as follows: annual and biennial – 113 pcs/m^2, red clover – 10 pcs/m^2, perennial – 8 pcs/m^2, or 87, 7 and 6% of their total amount, respectively. Due to high weed infestation, spring wheat crops during their tillering stage were treated with herbicide against dicotyledonous weeds.

After herbicide application, the subsequent state of crops depended significantly on the further mode of moistening during growth period. So, in dry 2013, single weeds were found in spring wheat crops before its harvest (table 3).

TABLE III. GENERAL WEED INFESTATION OF SPRING WHEAT SOWING BEFORE HARVEST DEPENDING ON FALL PLOWING METHOD, PCS/M^2

Tillage method	***Year***			***Average***
	2013	***2014***	***2015***	
Moldboard plowing (control)	2.4	45	8.9	19
Deep chisel plowing	1.8	55	8.8	22
2-row disk harrow	1.8	71	7.1	27
Erosion-preventing tillage	1.9	89	6.6	33
4-row disk harrow	1.9	78	9.6	30
Average	2.0	68	8.2	26
LSD_{05}	$F_f < F_{05}$	$F_f < F_{05}$	$F_f < F_{05}$	$F_f < F_{05}$

In favorable 2014, there was large density of weeds that appeared in the second half of growth season but these plants were in the ground layer and did not significantly affect spring wheat yield. In 2015, with dry first half of growth season, weeds rarely appeared after herbicide applying.

Studied methods of fall tillage applied after disk pre-tillage of clover field did not have any significant effect on the density of weeds.

V. Dependence of Spring Wheat Yield on Tillage

In Middle Cis-Ural region, due to limited growth season, early ripening and midearly varieties of spring wheat are predominantly used. These varieties cannot temporarily slow their development due to adverse conditions and then again continue growth and development. Negative factors cause irreparable damage for such varieties. It happened in dry 2013 when, during acute precipitation deficit and weak water-holding capacity of soil, the level of its humidity in plowing layer, from the heading during the start of grain filling, fell below the moisture level of permanent wilting (below 5.7%). Under these conditions, a low yield was obtained (Table 4).

TABLE IV. Spring Wheat Productivity Depending on Fall Plowing Method, t/ha

Tillage method	Year			Average
	2013	*2014*	*2015*	
Moldboard plowing (control)	1.11	4.01	2.12	2.41
Deep chisel plowing	1.08	3.76	2.05	2.30
2-row disk harrow	0.84	3.57	1.87	2.10
Erosion-preventing tillage	0.76	4.00	1.97	2.24
4-row disk harrow	0.97	4.12	2.20	2.43
Average	0.95	3.89	2.04	2.30
LSD_{05}	0.30	0.34	0.65	0.29

Under favorable humidity during the growth period of 2014, a good yield level was achieved using the same variety, with the same previous crop and the same soil – on average about 4 t/ha.

Dry first half of 2015 growth season led to less productive main stems, and precipitation at the beginning of the second half of growth season caused the formation of a second stem layer – some of which managed to form grain, and some turned out to be non-productive.

In the course of analysis of the effect of fall tillage methods, it should be noted that most of them provided almost the same yield compared to conventional moldboard plowing. Only in dry 2013, erosion-preventing tillage using KPE-3.8 and in favorable 2014 2-row disk harrow using BDT-3.0 led to a significant decrease in yield.

On average, over three years, a significant decrease in the yield of spring wheat after 2-row disk harrow using BDT-3.0 in comparison to conventional moldboard plowing using PLN-5-35 was due to a significant decrease in the mass of 1000 grains by 2.4 g (control – 34.2 g; LSD_{05} = 1.5 g) and in ear productivity by 0.08 g (control – 0.57 g; LSD_{05} = 0.08 g).

Studied methods of fall tillage, in addition to the influence on yield, are characterized by different operating width and speed of unitizing during technological operations what results in different performance. The calculation of spring wheat cultivation economic efficiency showed that all the applied methods of fall tillage were profitable. But if we compare it with moldboard plowing, the profitability of the technology including erosion-preventing deep chisel tillage with PCh-2.5 was 17% lower than moldboard plowing, 2-row disk harrow using BDT-3.0 was higher by 2%, erosion-preventing tillage using KPI-3.8 was higher by 7%, 4-row harrow using KMBD 3×4P was higher by 22%.

VI. Conclusions

Eroded low-humus sod-podzolic soils of the Cis-Ural region have weak strength of aggregates which are easily destroyed during soil moistening what results in significant soil consolidation which does not depend on the applied fall tillage method.

Studied fall tillage methods had no influence on weed infestation of spring wheat crops which due to the large stock of weed seeds in the soil significantly depends on the soil moistening regime during growth period.

A good yield of spring wheat can be obtained using different methods of fall tillage but, taking into account economic efficiency, preference should be given to minimal tillage methods.

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