Influence of tillage tools on agrophysical indicators of soil fertility and rice productivity

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Abstract

Under the Kyzylorda region, the zonal technology of the tillage system for rice provides for up to 8–10 passes of various units in the same field. The technologies used are often based on the use of obsolete machines, which leads to many negative developments. According to the scheme of field experiments, a traditional plow PLN-5-35 (control) and a swing plow Lemken Juwel 7 have been studied during fall plowing. It was found that the use of the Lemken Juwel 7 swing plow contributed to base on, obtaining the ridges coefficient of 1.09 due to the same size and shape of the layers and their location at the same distance, while in the check this figure was 1.15. The use of the Lemken Juwel 7 swing plow and the Horsch Terrano 4 FX cultivator in the tillage system of meadow-boggy soils for rice in the conditions of the Kyzylorda region contributes to an increase in yield by an average of 0,71 t/ha.

Introduction

Kyzylorda region is the main rice-producing region in the Republic of Kazakhstan with a total area of the rice irrigation system of 188.2 thousand hectares. Rice is annually cultivated on an area of 80–85 thousand hectares with a saturation of rice crop rotation of about 60.0% [1]. Over the past 8–10 years, the average yield of rice grain has increased from 42.5 to 53.4 c/ha. According to the statistics of 2020, 86.2 thousand tons of rice products worth 24.0 million dollars were exported to Russia, Kyrgyzstan, Belarus, Azerbaijan, Mongolia, Tajikistan, Ukraine, Turkmenistan and Iraq [2]. In the future, it is planned to export rice from the region to France [3].

This became possible due to the introduction of new high-yielding varieties of domestic and foreign selection, as well as improvement of the technology of their cultivation. Gross rice production in 2020 amounted to 551.3 thousand tons and can be increased, first of all, by equipping rice farms with modern tillage tools [2].

However, despite the increase in rice grain yields, its cost price remains high and averages 72.5–75.0 thousand KZT per 1 ton in the Kyzylorda region. Labor costs during its production are much higher when cultivating other crops of rice rotation (wheat, barley, soya, sunflower). So, on average in the region, labor costs for the production of 1 ton of rice is 5–6 man-days, and for the production of 1 ton of wheat – 1.2–1.5 man-days.

The reason for this situation, along with the well-known factors of an economic nature, is the lack of scientific development of many issues of tillage systems for rice. Therefore, in the structure of costs for growing this crop, a large share (about 20.9–22.3%) is taken by soil preparation for sowing [4].

A significant number of operations on soil preparation for rice sowing is explained by the mandatory fulfillment of agrotechnical requirements for the primary and secondary tillage, which include: regulation of oxidation-reduction processes in the plowing horizon, creation of a granular-dusty topsoil, which ensures sowing rice seeds to a depth of 1.5-2 cm, leveling the surface of the field with an accuracy of ± 3–5 cm, and killing of weeds [5, 6].

The technology of the primary and secondary tillage for rice in the Kyzylorda region includes the following process operations (Table 1). Fall plowing is carried out in the fall following the harvest of rice and crop residues. During such plowing, rootstock and tubers of weeds are brought to the surface and killed from frost or from drying out in the winter-spring period. Fall-plowed fieldfare left in clods for the winter [7].

Table 1
Process scheme of the primary and secondary tillage in the Kyzylorda region (predecessor: rice by rice)

Process operations	**Agricultural machinery and tools**	**Time frame**	**Agrotechnical standards**
Primary tillage			
1. Fall moldboard plowing	Mounted, semi-mounted and trailing plows in the unit: PLN-5-35 (mounted share plow) + KhTZ (Kharkov Tractor Works)-150K; PLN-8-35 + K-701	September-October	To a depth of 27–30 cm (25–27 cm is allowed). Deviations from the set depth – no more than ± 2 cm
Secondary tillage			
2. Disk fall plowing	Disk harrows in the unit: BDT-3 (heavy disk harrow) + KhTZ-150K; BTD-7 + K-701	April	To a depth of 16–18 cm
3. Surface leveling of check	Laser land levelers in the unit: Mara 50MD + KhTZ-150K, scraper D569 + KhTZ-150K	April	Levelling the surface with an accuracy of ± 2–3 cm
4. Application of mineral fertilizers (50–70% of the total dose of nitrogen and 100% of phosphorus)	Mineral fertilizerdistributors in the unit: RMG-3 + MTZ-82 (Minsk Tractor Works); mounted Akkord + MTZ-80; Amazone+MTZ-80	3rd decade of April-May	Uniform distribution of fertilizers over the check surface
5. Incorporation of mineral fertilizers	Disk harrows in the unit: BDT-3 + KhTZ-150K; BDT-7 + K-701	3rd decade of April-May	Uniform incorporation of fertilizers to a depth of 8–10 cm
6. Surface milling with tandem disk harrowing	Millers, tooth harrows in the unit: BZTU-6 (universal tractor tooth harrow) + 150K (when using a laser land leveler, milling can be excluded)	3rd decade of April-May	Complete brakingof lumps and fieldevenness
7. Presowing press work	ZKKSh-6 (star-wheeled roller) + MTZ-82	3rd decade of April-May	Complete brakingof lumps and fieldevenness

In spring, with the beginning of field work, disk fall plowing is carried out with BDT-3, BDT-7 disc harrows in 2 tracks to a depth of 16–18 cm. After disking, presowing leveling is performed with D-719 or Mara 50 MD land levelers in two tracks. Further, nitrogen and phosphorus fertilizers are applied, which are incorporated in the soil to a depth of 8–10 cm also with BDT-3, BDT-7disc harrows. After the incorporation of mineral fertilizers, before sowing, press work is carried out with star-wheeled rollers of the ZKKSh-6 type. At the beginning of sowing rice seeds, the field should be completely leveled and the soil should have a fine crumbly structure.

In the Kyzylorda region, in contrast to the Krasnodar Territory, where after sowing rice seeds, mandatory post sowing rolling of the field is carried out in order to evenly embed the seeds in the soil to a depth of 1.5 cm [8], this operation is not carried out due to the high salinity of rice checks [9]. As practice shows, excessive over-compaction of the soil contributes to the bringing up of salts to the surface of the field and makes it difficult to wash them out from the plowing layer.

As can be seen from Table 1, according to the adopted technology of rice cultivation, the units pass through the field 8–10 times, and all the techniques of the primary and secondary tillage are carried out mainly by machinery and tools, the use of which is not always justified, and leads to an increase in energy and financial costs. Therefore, the use in rice crop rotation of the zonal recommended technology for tilling meadow-boggy soils, developed in 2011 [7], currently does not ensure the realization of the potential of the soil and climatic conditions of the Kyzylorda region, as well as the genetic abilities of new rice varieties [10].

Especially this problem of the tillage system is relevant for farm and peasant holdings of the Kyzylorda region, which have technological complexes of machines consisting of low-performance single-operation machines. Their use does not allow to fully carry out operations to prepare soil for sowing in a timely manner and with high quality. This problem can be solved by using combined tillage units.

In modern conditions, rice farms of the region, along with traditional tillage machines, with the arrival of the dealer companies Eurasia Group Kazakhstan and ST AGRO in the region, began to acquire more often swing plows, combined units of a new generation. Thus, since its foundation in 2000, ST AGRO has been a reliable partner in the field of supply and service maintenance of agricultural machinery in Kazakhstan. Since 2014, it has been part of the Royal Reesink group in the Netherlands. ST AGRO has 13 branches, covering all regions of Kazakhstan, including the Kyzylorda region and supports on all purchase and service issues of high-quality equipment CLAAS, HORSCH, Valley, etc. [11, 12].

Eurasia Group Kazakhstan began its activity in the agricultural market of the Republic of Kazakhstan in 2002, becoming the official distributor of the company John Deere. For more than 16 years, Eurasia Group Kazakhstan has been supplying Kazakhstan farmers with the most modern, innovative, productive John Deere equipment, has a fairly developed dealer network (more than 50 companies), and owns a network of service centers with warehouses of spare parts in all agricultural regions of Kazakhstan [13].

Currently, the leading farms in the region for the primary tillage use more productive swing plows of the Lemken Juwel 7 type, which save fuel and lubricants and time by reducing the length of idle passes on turns. The operational leveling is carried out by foreign soil levelers of the Mara 50MD type, which have twice the stability and speed compared to the machines of the previous generation. High accuracy of leveling on these levelers is achieved through the use of a laser control system.

In the market of tillage machinery, agricultural tools that perform several operations in one pass and combined tools are becoming more and more popular. So, instead of BDT-3.0 disc harrows, heavy disc harrows with individual installation of working attachments of the BDM-Agro type, Horsch Terrano 4 FX cultivators, which have press rollers as additional working attachments, are used for tillage.

The issues of agrotechnical assessment of various foreign-made tools for the primary and secondary tillage for rice in this region have not been practically carried out. In this regard, the establishment of the effectiveness of the use of various tillage tools of a new generation, which are on the balance sheet of rice farms in the region, is an urgent task of production and science.

The object of the paper is to establish the influence of the effectiveness of the use of different tillage tools on the agrophysical properties of meadow-boggy soils and rice productivity in the conditions of the Kyzylorda region.

Research Conditions And Methodology

The experimental part of the research on rice cultivation was carried out in the Karaultobe experimental station of the Kazakh Research Institute of Rice Production named after Y. Zhakhaev, located 10 km north-east of Kyzylorda city [14].

The object of research was a new promising cultivar of rice Syr Suluy of local selection (the originator is the Kazakh Scientific Research Institute of rice growing named after I. Zhakhayev) with the following characteristics: growing season is 105–110 days, average height of plants is 95–100 cm, length of the panicle is 18–21 cm, number of grains in the panicle is 90–110 pieces, weight of 1000 grains is 35–36 g, potential yield is 8.5-9.0 t/ha, filminess of the grain is 17–18%, grain viltreousnessis 95%.

Field studies were carried out in the rice crop rotation link. According to the particle-size distribution the soil of the experimental field belongs to heavy loamy, fine-pored and slightly crumbling's per the N. A. Kachinsky method. According to its granulometric composition, the soil belongs to silty heavy loams and clays.

The water-physical properties of the soil have a great influence on the growth and development of plants, since they determine the water and air regimes. The bulk density in the plowing layer of the experimental field after the rice harvest is about 1.34 g/cm^3, but as a result of increasing the depth of sampling, there is a slight increase to 1.43 g/cm^3. High total porosity is observed in the upper, more humus horizons – 56.1% (Table 2).

Table 2
– Initial water-physical properties of meadow-boggy soils of the experimental field (average for 2019–2020)

Depth of sampling, cm	Specific weight, g/cm^3	Soil density, g/cm^3	Soil hardness, g/cm^3	Common layer porosity, %
0–20	2.61	1.34	5.4	56.1
20–40	2.63	1.38	11.2	51.4

The growth and development of plants largely depends on the agrochemical indices of the soil. Of particular importance are such indices as humus content, mobile nitrogen and phosphorus, as well as exchangeable potassium, which all combined means the potential soil fertility. The study of the agrochemical properties of the experimental field indicates low humus content (0.95 – 0.84%) and a decrease in its content down the profile. The soil reaction of the plowing layer is high– pH 7.8 (Table 3).

Table 3
– Initial agrochemical composition of meadow-boggy soils of the experimental field (average for 2019–2020)

Depth of sampling, cm	Humus, %	Soil solution reaction, pH	Mobile nitrogen (N), mg/kg	Mobile phosphorus (P_2O_5), mg/kg (according to Machigin)	Exchangeable potassium (K_2O), mg/kg (according to Machigin)
0–20	0.95	7.8	15.7	15.3	142.2
20–40	0.91	7.7	13.9	14.1	120.0

The low content of organic matter in the soil also determines the low content of mobile and exchangeable forms of plant food elements. Thus, the content of readily-available nitrogen forms at a plowing depth of 0–20 cm does not exceed 15.7 mg/kg of soil, available phosphorus – 15.3 mg/kg of soil and exchangeable potassium – 142.2 mg/kg of soil in the plowing layer.

The agricultural machinery, the composition of tractors and tillage tools that perform the process operationsperformed in the experiment variants are shown in Table 2. The agricultural machinery in the experiment corresponds to the scientific farming system recommended for the Kyzylorda region (Table 4).

Table 4
Agricultural machinery, the composition of tractors and tillage tools that performed the process operationsin the variants of experiments

1. Fall plowing to a depth of 25–27 cm			
KhTZ-150K + PLN-5-35 *(control)*		Claas Axion 820 + Lemken Juwel 7	
2. Disk fall plowingto a depth of 16–18 cm			
KhTZ-150K + BDT-3 in two tracks *(control)*	KhTZ-150K + BDM-Agro	KhTZ-150K + BDT-3 in two tracks	KhTZ-150K + Horsch Terrano 4 FX
3. Surface levelling of check			
KhTZ-150K + Mara 50MD	KhTZ-150K + Mara 50MD	KhTZ-150K+ Mara 50MD	KhTZ-150K + Mara 50MD
4. Application of nitrogen-phosphorus fertilizers*			
MTZ-80 + Akkord	MTZ-80 + Akkord	MTZ-80 + Akkord	MTZ-80 + Akkord
5. Incorporation of nitrogen-phosphorus fertilizers to a depth of 8–10 cm			
KhTZ-150K + BDT-3 *(control)*	KhTZ-150K + BDM-Agro	KhTZ-150K + BDT-3	KhTZ-150K + Horsch Terrano 4 FX
6. Presowing press work			
MTZ-82 + ZKKSh-6 *(control)*	Not applicable	MTZ-82 + ZKKSh-6	Not applicable

Note *****: nitrogen fertilizers (carbamide) were applied fractionally, N_{60}kg of active agent – before sowing, N_{60} kg of active agent – in the tillering phase, phosphorus ones – in the form of simple superphosphate (with a phosphorus content of 20.0%). The calculated doses of mineral fertilizers were carried out taking into account the removal of nutrients by the crop and the utilization coefficients from the soil and fertilizers.

The total area of the experimental field is 10,800 m^2, the area of one registration plot is 600 m^2 (12x50 m, the plot width is a multiple of the operating width of tillage tools), the allocation of plots is systematic, the replication is three-fold [15].

In the experiments, with the exception of presowing press work, the recommended rice cultivation technology was used [7]. The seed application rate is 7.0 million viable seeds/ha. Irrigation regime is shorted flooding with the use of herbicides.

The list of the studied tillage tools and their brief description.

Tillage plows:

PLN-5-35 is a mounted share plow having five plowshares with an operating width of one bottom of 35 cm, designed for plowing to a depth of 30 cm for grain and industrial crops of various soils [16].

Lemken Juwel 7 is a swing plow designed for tilling large tracts of arable land with incorporation of plant residues (overturning the furrow slice) and intensive loosening. The unique feature is two rows of shares: right and left blade. Mounted version, the number of bottoms is 5 with an operating width of one bottom of 40 cm [17, 18].

Tools for secondary tillage:

BDT-3 is a heavy disc harrow with an operating width of 3.0 m, designed for weed destruction and crushing crop residues, for cutting soil layers after or instead of plowing, tillage after harvesting thick-stemmed row crops [19].

ZKKSh-6 is a star-wheeled roller with an operating width of 6.0 m, designed for presowing and post sowing press work, loosening of the upper and compaction of the surface soil layers, breaking clods, breaking the soil crust and partial levelling of the plowed field surface [20].

BDM Agro-4,2x3 is an advanced disc harrow with an operating width of 4.2 m (disk header), designed for traditional and minimal primary and secondary tillage for grain, industrial and forage crops. In one pass, the harrow crushes and embeds plant residues of the predecessor and weeds into the soil, creates a loosened and levelled soil layer, and incorporates the applied fertilizers [21].

Horsch Terrano 4 FX is a versatile three-row cultivator with an operating width of 4.0 m, designed for surface stubble tillage and intensive cultivation with high-quality mixing of crop residues to a tillagedepth of 5 to 30 cm [22].

Methods of determining the quality of tillage in experiments:

Soil density (g/cm^3) was determined by the volume-weight method according to N.A. Kachinsky (samples were taken using a cylinder with a volume of 100 cm^3 from layers 0–10, 10–20 and 20–30 cm); specific soil density (g/cm^3) was determined by the pycnometer method. The density of the treated soil layer was determined in five places at equal distances from each other along the diagonal of the field. The determinations were carried out before fall plowing and after presowing press work [23, p. 31].

Soil hardness (g/cm^2). The determinations were carried out before fall plowing and after presowing press work [23, p. 53].

Ridgeness (height of the ridges) of the plowed field surface is determined by measuring the height of the ridges using a strip and a scale after fall plowing. On the surface of the field across the direction of tillagealong the entire working width of the unit, the height of all ridges from the ridge base to the rodis measured with a scale. The allowed height of the ridges is no more than 5–6 cm [23, p. 300].

*Cloddiness (clumsiness) of the plowed field*is determined by the imposition of a frame of 100x100 cm, divided after 25 cm by a stretched wire. Then the number of clods and lumps with a diameter of 6–10 cm or more and the area they occupy per 1 m2 of the frame are taken into account. The determination is carried out with a 5-foldreplication along the diagonal of the field. The area under the clods is allowed no more than 15 ... 20%. If, on average, there are more than five clods per 1 m^2 of the plowed field, then the quality of plowing is considered poor [23, p. 296].

Soilstructure is determined by a set of sieves by dry scattering (by the method of N. I. Savvinov). Sieves with hole diameters 10, 7, 5, 3, 2, 1, 0.5 and 0.25 mmare used, connecting them in a sequential set – from a larger diameter to a smaller one [23, p. 34].

Phenological observations.

During the growing season of rice, the following records and observations were carried out: The water level in the checks was measured using water gauges.

Field germination and density of rice plants were determined using a 0.25 m^2 frame by counting the number of plants and straws of rice in it. Counting was carried out on all plots of experiments on seedlings and after harvesting rice.

Phenological observations were carried out on fixed plots in 6 fold replication with 25 plants per plot. The beginning of the phase was taken as its onset in 10% of plants, mass onset in 75% of plants.

Weather conditions. The year 2019 was characterized by higher temperatures than the long-term annual average. The average monthly air temperature during the active growing season (May-September) was higher than the long-time annual average indicator by 0.1–3.9^{0}C (Table 5). In July, the hottest and the driest weather of the summer season prevailed – the average air temperature was + 31.7^{0}C. From January to March, the highest amount of precipitation has fallen, equal to 82.0 mm, which exceeds the norm by 33.0 mm or 40.2%. Light precipitation in September-October (6.0 mm) has not prevented rice harvest [24].

The year 2020 was also abnormally hot and mostly dry in the summer. Temperature conditions also determined the terms (dates) of the transition of the average daily air temperature through + 10^{0}C compared to long-term annual ones. The general increase in air temperature during this period contributed to the warming of the soil to optimum temperatures and the sowing of rice 5–7 days (April 10–17) earlier than long-term deadlines. Noticeable deviations from long-term norms in the amount of atmospheric precipitation were observed almost for the entire calendar year.

Table 5
Meteorological indicators for the years of research on observations of the meteorological station Kyzylorda City (2019–2020).

Months	2019				2020			
	Air temperature, ^0C		Amount of precipitation, mm		Air temperature, ^0C		Amount of precipitation, mm	
	Average monthly	Deviation from the norm	Average monthly	Deviation from the norm	Average monthly	Deviation from the norm	Average monthly	Deviation from the norm
January	-3.3	+ 3.5	19.0	0	-2.5	+ 4.3	19.0	0
February	-2.9	+ 2.1	29.0	+ 15.0	1.3	+ 6.3	27.0	+ 13.0
March	8.3	+ 6.8	34.0	+ 18.0	7.0	+ 4.3	0.4	-15.4
April	14.1	+ 0.8	5.0	-12.0	15.6	+ 2.3	29.0	+ 12.0
May	22.0	+ 1.7	7.0	− 10.0	23.5	+ 3.2	25.0	+ 8.0
June	27.5	+ 1.4	3.0	-7.0	27.2	+ 1.1	4.0	-6.0
July	31.7	+ 3.9	3.0	-3.0	29.7	+ 1.9	4.0	-2.0
August	25.7	+ 0.1	0.6	-3.4	26.3	+ 0.7	0.5	-3.5
September	18.6	0	2.0	-2.0	17.9	-0.7	0	-4.0
October	12.6	+ 2.5	4.0	-6.0	10.0	-0.1	0.4	-9.6
November	1.8	-0.6	5.0	-12.0	-1.4	-3.2	13.0	-4.0
December	-0.9	+ 3.8	39	+ 22	-11.0	-6.3	2.0	-15.0

Thus, the weather conditions during the research period were generally typical for the territories of the central zone of the Kyzylorda region and the air temperature regime was favourable for cultivation of not only rice, but also other crops of rice rotation.

Results And Discussion

Soil structure and its agronomic value. The formation of structural aggregates is a complex natural process, and mechanical effects on the soil with tillage tools, as a rule, destroy its structure. In this regard, one of the main tasks of tillage is to minimize the destruction of the structure and create the best conditions for its accelerated recovery. Depending on the size of the aggregates, the soil structure is subdivided (according to P.V. Vershinin) into the following groups: cloddy (aggregates over 10 mm), macrostructure (10-0.25 mm), coarse microstructure (0.25 – 0.01 mm), and fine microstructure (less than 0.01 mm). Agronomically valuable fractions are considered to be all fractions in the range from 10 to 0.25 mm. The soil structure is of high quality when the amount of agronomically valuable particles in the soil is more than 55%. Aggregates larger than 10 mm are clods and the cloddy structure, as known, is far from the best condition of the soil, just as the dominance of particles smaller than 0.25 mm of the silty part of soil aggregates. Therefore, the following qualitative assessments of the structure are used based on the number of aggregates of this very agronomically valuable range, 10-0.25 mm.

Structure coefficient (C_{str}) is determined by the following formula [25]:

$$C_{str} = \frac{\sum (10 - 0{,}25mm)}{\sum (> 10mm, \ < 0{,}25mm)}$$

Agronomically correct choice of a particular system of basic and presowing soil, timely and high-quality performance of all scientifically based operations, taking into account specific conditions, is a mandatory requirement and an important prerequisite for obtaining high and sustainable rice yields.

Fall (primary) plowing. In the Kyzylorda region, rice production is concentrated mainly on meadow-boggy soils, characterized by a low level of natural fertility, contains little humus–0.74–1.55%, total nitrogen – 0.084–0.106%, and total phosphorus – 0.149–0.171% [26]. Such soils, when poorlytilled, lead to a deterioration of its agrophysical properties, which negatively affects the size and quality of the rice yield.

The quality of fall plowing of the soil is largely determined by the soil and climatic conditions, the technical condition of the unit, the timing of the work, the skill of the machine operator, as well as the correct choice of tillage tools. In a field plowed since autumn, in spring, the workability of soil begins faster, which makes it possible to start its presowing preparation earlier and carry out sowing in the optimal agrotechnical terms.

In our studies, fall plowing of the soil on the experimental field was carried out in agrotechnical terms after the harvesting of rice and crop residues (the second decade of October).

As a criterion for assessing tillage, the ridgenessof the plowed field (height of the ridges) and thecloddiness (number of clods and area under clods) were determined, the special significance of which these indicators acquire in fields intended for sowing rice, the cultivation of which requires careful soil preparation.

The first observations of the experiments showed that when plowing with the Lemken Juwel 7 swing plow, the layers of meadow-boggy soils were tightly and evenly adjoined to each other, and the ridges were clearly defined. Therefore, due to the formation of the same size and shape of the layers, as well as their location at the same distance from each other, the ridgenesscoefficient in these fields was 1.09. This indicator was somewhat higher (1.15) on plots where plowing was carried out with the PLN-5-35 traditional plow (Table 6).

Table 6

Influence of various tillage tools on the ridgeness and cloddiness of meadow-boggy soils (average for 2019–2020)

Primary tillage to a depth of 25–27 cm	**Ridgeness, cm**		**Ridgeness coefficient**	**Cloddiness, pcs/m^2**	**Area under clods, m^2**
	profile line length	**projected length***			
PLN-5-35	13.8	12.0	1.15	18.0	0.28
Lemken Juwel 7	13.1	12.0	1.09	17.2	0.16
Note: ***** – *the projected length is equal to the registration plot width, i.e. 12.0 m.*					

The fall-plowed field should not be excessively cloddy, since additional tilling of such a fall-plowed field with the help of heavy disc harrows and rollers does not always eliminate its flaws. In addition, poor-quality fall-plowed field creates additional difficulties in the spring, reducing the efficiency of subsequent operations of secondary tillage for the cultivated crop.

From the obtained experimental material, it follows that the number of clods (lumps of soil with a diameter of more than 5.0 cm) on the check surface of the experimental fields when plowing with the PLN-5-35 plow was 18.0 pcs/m^2, the occupied area was 0.38 m^2, slightly less – 17.2 pcs/m^2 was recorded when plowing with the Lemken Juwel 7 swing plow. However, in this variant, the smallest area occupied by them was noted, and, therefore, cloddiness was 0.16 m^2 (Fig. 1).

In general, the ridgeness coefficient and the number of clods on the surface of the plowed field largely depended not only on the physical condition of the soil, but also on the design features of the plows being compared. It should also be noted that when using the swing plow, there was no need to divide the checks into lots, as a result of which there were no back furrows and center ridges on it.

Secondary tillage (disk fall plowing). The correct system of secondary tillage for rice can only be carried out under the condition of good winter tillage. It should create an insulating layer on the soil surface in order to preserve soil moisture, eliminate compaction in the plowing layer, provoke weeds to germinate, create a grainy-silty topsoil that allows sowing rice seeds to a depth of 1.5-2.0 cm, and level the field surface with an accuracy of ± 3–5 cm.

Disk fall plowing to a depth of 16–18 cm with various tools was carried out in the spring at the onset of workability of the soil (2nd decade of April) on the experimental fileds, plowed with the PLN-5-35 and Lemken Juwel 7 plows. The results of the research indicate that various tillage tools influenced the natural processes of structure formation and led to a change in the content of agronomically valuable aggregates ranging in size from 10 to 0.25 mm (Table 7).

Table 7
Aggregate composition of the soil in a layer of 0–10 cm after disk fall plowing with various tools to a depth of 16–18 cm (%by weight of the sample), (average for 2019–2020)

Fall plowing	**Disk fall plowing to a depth of**	**Sizes of aggregates (mm) and their contents (%)**					**Structure coefficient**
	16–18 cm	**> 25**	**25 – 10**	**10 – 1**	**1-0.25**	**< 0.25**	
PLN-5-35 (control)	BDT-3 in two tracks (control)	30.5	37.5	27.8	5.3	0.9	0.49
	BDM-Agro	22.3	35.2	30.8	9.6	1.1	0.67
Lemken Juwel 7	BDT-3 in two tracks	25.8	36.4	30.6	8.4	0.8	0.63
	Horsch Terrano 4 FX	18.2	32.6	33.6	11.7	1.9	0.82
LSD_{05} (least significant difference)							0,05

The smallest quantityof agronomically valuable aggregates (33.1%) with a predominance of the cloddy fraction (30.5%), where BDT-3 was used in two tracks, was noted. It also follows from the data in the table that the use of combined tools such as BDM-Agro and Horsch Terrano 4 FX have promoted active crumbling of the plowing layer of soil, mixing of soil particles with plant residues, which is accompanied by the formation of fine soil particles. Thus, the share of cloddy aggregates (> 10 mm) accounted for 6.2–8.7%, and fine earth accounted for 19–23%. Lemken Juwel 7 + Horsch Terrano 4 FX is dominated by the 3–5 mm fraction.

In these variants, there was a tendency to an increase in the structure coefficient due to an increase in the content of agronomically valuable particles and a decrease in the number of fractions with a size of < 0.25.

*Secondary tillage.*Violation of the quality of presowing preparation of the soil surface leads to the formation of a waterlogged layer, deterioration of the water and air and thermal regime, deviation from the established sowing depth, which contributes to blindness in seedlings, a decrease in field germination and yield of cultivatedsmall-seeded crops.

Preference is given to those tools that have the ability to loosen and crumble the plowing horizon of soil so that before sowing in a layer of 0–10 cm there are no fractions larger than 25 mm, i.e. exceeding the seeding depth of rice by its sizes.

When studying the physical properties of the soil in the 0–10 cm layer in comparison with disk fall plowing to a depth of 16–18 cm (Table 7), significant changes are observed in the structural and aggregate composition towards their improvement under the influence of different tillage tools. So, in the control variant, where the BDT-3 disc harrow (incorporation of nitrogen-phosphorus fertilizers) and the ZKKSh-6 star-wheeled roller recommended in the zone were used as surface tillage, the number of agronomically useful sizes was 50.7% (Table 8). In addition, on the control plots, in comparison with other variants of the experiment, a sharp differentiation was recorded between the cloddy (11.8%) and dusty fraction (2.1%).

Table 8
Aggregate composition of the soil in a layer of 0–5 cm before sowing rice (%, by weight of the sample), (average for 2019–2020)

Fall plowing to a depth of 25–27 cm	**Disk fall plowing to a depth of 16–18 cm**	**Secondary tillage to a depth of 8–10 cm**	**Sizes of aggregates (mm) and their contents (%)**					**Structure coefficient**
			> 25	**25 – 10**	**10 – 1**	**1-0.25**	**< 0.25**	
PLN-5-35 (control)	BDT-3 in two tracks (control)	BDT-3 + ZKKSh-6 (control)	11.8	37.4	36.6	14.1	2.1	1.02
	BDM-Agro	BDM-Agro	6.8	38.4	42.6	10.5	1.7	1.13
Lemken Juwel 7	BDT-3 in two tracks	BDT-3 + ZKKSh-6	4.7	40.2	44.1	9.6	1.4	1.15
	Horsch Terrano 4 FX	Horsch Terrano 4 FX	2.1	9.6	48.2	11.2	0.9	1.46
LSD_{05} (least significant difference)								0,08

The analysis of the results obtained by us showed that in the soil tilled with the disk header BDM-Agro 3x4, the content of aggregates ranging in size from 1 to 10.0 mm in a layer of 0–5 cmwas 53.1%. This is explained by the specifics of the work of the BDM-Agro concave disks, itis good to crumble the soil and crush its buckshot structure, and the slat-spiral rollers, installed at the back, finally breaking the soil into even lumps, leave a perfectly flat loose surface (Fig. 2). At the same time, it was noticed that when using the Horsch Terrano 4 FX cultivator, an increase in the amount of agronomically valuable structural aggregates was followed by a decrease in the silt fraction up to 0.9% of the total amount of aggregates.

One of the reasons for the positive effect on the soil structure of the Horsch Terrano 4 FX cultivator is due to the prolonged presence of the cultivated soil in the working area and the special shape of the tines, which allows achieving better mixing quality. In addition, relying on the tractor mounting mechanism in the front and the compaction roller in the back, this cultivator on the experimental fields made it possible to maintain strictly the specified placement depth of mineral fertilizers (8–10 cm).

It should also be noted that when cultivating the soil with the Horsch Terrano 4 FX cultivator, 59.4% of the aggregate composition remained in the surface layer, not deeper than 5 cm. After tilling with the BDT-3 disc harrows, these aggregates, for the most part, were embedded on the bottom of the furrow, and hard-to-break clods were partially tilted out on to the soil surface. Therefore, in the fields tilled with these tools, the 0–5 cm layer contained fractions larger than 25 mm.

The soil structure coefficient, at a depth of 0–5 cm, according to the variants of the experiment has been in the range from 1.13 to 1.15, this indicates that in all variants, except for the control one, the soils have a good aggregate state before sowing, with the exception of the variant with plowing using a swing plow, which has an excellent aggregate state of 1.46.

The content of the most agronomically valuable aggregates of the plowing layer of soil was (0.25-10.0 mm) according to the variants in the range of 55.3–60.5%, which, firstly, characterized a good aggregate state, since the values were included in the group of 40–60%; secondly, there were no significant differences between the tillage methods in comparison with the control variant (PLN-5-35).

The bulk density has a soil-zonal pattern and depends on the content of humus in it, its granulometric composition and structure. Rice, like most agricultural plants, grows and develops better at a soil density of 1.1–1.3 g/cm^3. In the studies of N. S. Kandaurov and other researchers, it was found that the rice yield decreases both on loose (< 0.9 g/cm^3) and on dense (more than 1.3 g/cm^3) soil within the range of 16–32% [27].

As a result of soil analysis, it was revealed that the freezing of the soil plowed in autumn under the influence of the weather conditions of the winter season contributed to its natural loosening. In this connection, by the beginning of the spring presowing cultivations (2-nd decade of April), the soil density was relatively the samein all variants of the experiment and amounted to 1.25–1.26 g/cm^3 (Table 9).

Table 9

Soil density in the 0–20 cm layer of the plowing horizon under rice, g/cm^3 (average for 2019–2020)

Fall plowing to a depth of 25–27 cm	Disk fall plowing to a depth of 16–18 cm	Secondary tillage to a depth of 8–10 cm	Soil density in the 0–20 cm layer, g/cm^3	
			Before disk fall plowing	Before sowing
PLN-5-35 (control)	BDT-3 in two tracks (control)	BDT-3 + ZKKSh-6 (control)	1.26	1.30
	BDM-Agro	BDM-Agro	1.26	1.28
Lemken Juwel 7	BDT-3 in two tracks	BDT-3 + ZKKSh-6	1.25	1.30
	Horsch Terrano 4 FX	Horsch Terrano 4 FX	1.25	1.27

Further study of soil density in the 0–20 cm layer indicates that the studied tools and tillage methodshad an unequal effect on the soil density ratio before rice sowing. Thus, the highest soil density in the 0–20 layer was recorded on the control plots, where the traditional technology with commercial tools was used (1.30 g/cm^3), while the disk fall plowingto a depth of 16–18 cm using the BDM-Agrodisk headerfollowed by disking and rolling, significantly reduced theseratio by an average of 0.02 g/cm^3. A slight increase in density in the control variant of the experiment could be explained by the fact that there were a large quantity of coarse fractions (Table 7), which together had a fluffy consistency.

In the fields where fall plowing was carried out with the Lemken Juwel 7 swing plow, the soil density of the disk fall plowingto a depth of 16–18 cm with BDT-3 and two cultivations with the same tool after applying mineral fertilizers was 1.28 g/cm^3. In the variant where the incorporation of mineral fertilizers and rolling was carried out in one pass with Horsch Terrano 4 FX, the soil density was minimal – 1.27 g/cm^3.

Thus, analyzing the data on the density of the soil consistency, it should be noted that by the spring, under the influence of meteorological factors in the autumn-winter period, the soils occupied by rice in the conditions of the Kyzylorda region, despite the plows used, acquire an optimum value. Minimization of presowing cultivation of meadow-boggy soils by combining disking and rolling in one technological process leads to a decrease in the density of the 0–20 cm soil layer by an average of 0.02–0.05 g/cm^3.

When preparing the soil for sowing rice, it is necessary to take into account the index of its hardness. High hardness worsens the physical-mechanical and agrophysical propertiesof the soil, hinders the germination of plants, prevents the development of their root system, and requires additional energy consumption during its cultivation [28, 29].

The results obtained show that before the start of fall plowing, i.e. after harvesting rice, the soil had a slight hardness in creasing with the depth in all variants of the experiment. After all the winter and presowing cultivations, by the beginning of rice sowing, only the 0–5 cm layer (4.0-4.3 kg/cm^2) remained uncompacted, and deeper in the 5–10 cm layer, the hardness value increased sharply in comparison with the initial one, and was on average 11.6–12.6 kg/cm^2 in all variants of the experiment, regardless of the tools used and the number of operations performed, in the 10–20 cm layers, the hardness value was 12.0–13.0 kg/cm^2, which was a good indicator for rice (Table 10).

Table 10

Soil hardness in different layers of the plowing horizon under rice, kg/cm^2 (average for 2019–2020)

Fall plowing to a depth of 25–27 cm	Secondary tillage		Sample depth, cm					
	Disk fall plowing to a depth of 16–18 cm	Diskingto a depth of 8–10 cm and rolling	before fall plowing			before sowing		
			0–5	5–10	10–20	0–5	5–10	10–20
PLN-5-35 (control)	BDT-3 in two tracks (control)	BDT-3 + ZKKSh-6 (control)	4.3	5.8	5.6	5.1	12.6	13.0
	BDM-Agro	BDM-Agro	4.3	5.8	5.6	5.0	12.2	12.8
Lemken Juwel 7	BDT-3 in two tracks	BDT-3 + ZKKSh-6	4.0	5.6	5.6	4.8	11.8	12.1
	Horsch Terrano 4 FX	Horsch Terrano 4 FX	4.0	5.6	5.6	4.6	11.6	12.0

Thus, the results of research on the effect of tillage tools on agrophysical properties show that on meadow-boggy soils, the incorporation of mineral fertilizers with further soil rolling can be completely replaced with modern tools such as BDM-Agro and Horsch Terrano 4 FX.

The yield of an agricultural crop depends on the number of plants per unit area and their productivity. The first component of the yield structure is largely determined by the field germination of seeds. Field germination is the number of seedlings expressed as a percentage of the number of germinating seeds sown.

In the Kyzylorda region, throughout the development of rice growing, a stable increase in yield is limited by the low field germination of rice seeds, which does not exceed 30% [10]. Therefore, obtaining optimal seedlings in terms of density in the amount of 300–350 plants per 1 m^2 is one of the current problems of rice sowing, the successful solution of which largely depends on how correctly an integrated tillage system is made for specific conditions.

The different aggregate composition of the soil plays a significant role in the initial stages of growth and development of rice plants. The predominance of fractions of 1–10 mm in the sowing layer makes it possible to increase the field germination of rice seeds, reduce the number of days from sowing to emergence of seedlings, and provide favorable conditions for the formation of the root system. So, according to A.K. Butov, the presence of aggregates from 1 to 10 mm in size in the upper layer (0–5 cm), after sowing rice, doubles the field germination of seeds [30].

In our studies, the first seedlings of rice seeds on the experimental field appeared 5–7 days after sowing. As the first records showed, the primary and secondary tillage with different tools began to affect rice plants from seed sprouting, i.e. their field germination (Table 11).

In the course of fall plowing, where cultivation was carried out with the PLN-5-35 plow, the highest field germination of seeds of 218.2 pcs/m^2 was provided by the BDM-Agrodisk header, their smallest number of 204.2 pcs/$m^2$was in the control variant, where BDT-3 in two tracks was used. The lower germination of rice seeds on this field can be explained by the fact that during the initial flooding of the checks with water, soil fractions < 0.25 mm in size tighten the seeds, and > 10.0 mm cover the seeds after swelling. As a result, the rice seeds are at a greater depth, which, if there is a layer of water in the checks, the seedlings cannot overcome.

Table 11

Field germination of seeds and preservation of plants for harvestingrice depending on the tillage tools used (average for 2019–2020)

Fall plowing to a depth of 25–27 cm	**Disk fall plowing to a depth of 16–18 cm**	**Secondary tillage to a depth of 8–10 cm**	**Field germination**		**Preservation of plants for harvesting**	
			pcs/m^2	**%**	**pcs/m^2**	**%**
PLN-5-35 (control)	BDT-3 in two tracks (control)	BDT-3 + ZKKSh-6 (control)	204.2	30.6	135.7	66.5
	BDM-Agro	BDM-Agro	218.2	31.1	142.7	65.4
Lemken Juwel 7	BDT-3 in two tracks	BDT-3 + ZKKSh-6	219.0	31.2	146.0	66.6
	Horsch Terrano 4 FX	Horsch Terrano 4 FX	223.8	31.9	150.0	67.0
LSD_{05} (least significant difference)				0,72		0,81

From the above data it can be seen that in the experiments, the largest number of germinating rice seeds, 223.8 pcs/m^2, was obtained in the variant where fall plowing was carried out with the Lemken Juwel 7 swing plow, and disk fall plowing and secondary tillage was carried out with the Horsch Terrano 4 FX cultivator, i.e. where in the 0–5 cm soil layer the fractional composition was represented mainly by the size of aggregates from 1 to 10 mm. The number of sprouted plants in the variant using Lemken Juwel 7 and BDT-3 was 219.0 pcs/m^2.

Field germination, as known, is correlated with the index of the degree of plant preservation, which characterizes the number of plants preserved for harvesting as a percentage of the number of sprouted ones. In the course of research, we found that the preservation of rice plants before harvesting in all variants of the experiment, including control, did not have a significant difference and ranged within 65.4–67.0%. This indicator can be considered relatively optimal for the study area. The existing differences in 2..3 plants according to the variants of the experiment, in principle, reflect not the influence of the agrophysical properties of soils during the growing season, but the accuracy of the formation of the density of the rice plants.

Yield is the most important indicator of agricultural crops. Establishing the relationship between the yield and the agrophysical properties of the soil makes it possible to change them in the desired direction by improving the tillagesystem and the optimum set of tillage tools.

The analysis of the data obtained shows that, in general, the rice yield in all experiments has been formed to be quite high throughout the years of research. The results of the experiments once again confirm the effectiveness of using the Lemken Juwel 7 swing plow in conjunction with the Horsch Terrano 4 FX cultivator, where it provided the highest rice yield of 6,83 t/ha, and the yield increase was 0,71 t/ha compared to the control (Table 12).

Table 12

Rice grain yield depending on the tillage tools used, t/ha (average for 2019–2020)

Fall plowing to a depth of 25–27 cm	Disk fall plowing to a depth of 16–18 cm	Secondary tillage to a depth of 8–10 cm	Rice grain yield, t/ha	Addition to the control, c/ha
PLN-5-35 (control)	BDT-3 in two tracks (control)	BDT-3 + ZKKSh-6 (control)	6.12	-
	BDM-Agro	BDM-Agro	6.54	+ 0.42
Lemken Juwel 7	BDT-3 in two tracks	BDT-3 + ZKKSh-6	6.32	+ 0.2
	Horsch Terrano 4 FX	Horsch Terrano 4 FX	6.83	+ 0.71
LSD_{05} (least significant difference)			0.21	

This is primarily due to more optimal agrophysical properties and a high coefficient of soil structure (1.46) before sowing rice, and secondly, due to higher field germination of seeds in the studied variant.

Rice harvest accounting in the variant where the PLN-5-35 traditional plow was used for plowing, as well as the use of the BDM-Agrodisk headers disk, fall plowing, and incorporating mineral fertilizers with subsequent presowing rolling of the field also contributed to obtaining an additional yield in the quantity of 0,42 t/ha.

Conclusions

In the conditions of the Kyzylorda region, in order to ensure optimum agrophysical properties of meadow-boggy soils and obtain a consistently high yield of rice, it is advisable to carry out fall plowing with swing plows of the Lemken Juwel 7 type, and disk fall plowingand incorporation of mineral fertilizers with simultaneous rolling of the field surface should be performed with BDM-Agrodisk headers or with Horsch Terrano 4 FX cultivators.

Declarations

Data Availability

Data used in preparing this manuscript is available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Author information

Bekzathan Kultasov and Serik Bekzhanov contributed equally to this work.

Contributions

Bekzathan Kultasov, Serik Bekzhanov, Laura Tokhetova, Ibadulla Tautenov conceived the research, designed the experiments and performed the experiments; Bibugul Baizhanova, Nurali Nurgaliyev wrote the manuscript. The author(s) read and approved the final manuscript

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Figures

Figure 1

Fall plowing with the unit Claas Axion 820+ Lemken Juwel 7 a – general view of the unit; b – determination of cloddiness of the field with a counting frame

Figure 2

Incorporation of nitrogen-phosphorus fertilizers with the unit KhTZ–150K + Horsch Terrano 4 FX: a – side view; b – back view