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INFLUENCE OF TILLAGE TOOLS ON AGROPHYSICAL PARAMETERS OF MEADOW-BOGGY SOIL AND RICE PRODUCTIVITY IN KAZAKHSTAN

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SUMMARY

Zonal technology treatment of the soil system for rice cultivation comprised various operations carried out with tillage equipment types in the Kyzylorda Region, Kazakhstan. With the region's agriculture sector having a low technical base, the performance of these operations is mostly meager, which does not justify itself in the modern conditions of the agro-industrial complex's functioning. The presented studies sought to determine the influence of different tillage tools on the soil's plowing quality, agrophysical properties, and rice productivity, carried out at the Kazakh Scientific Research Institute of Rice Growing, named after I. Zhakhaev, Kazakhstan. The study observed the use of a "Lemken Juwel-7 reversible plough" contributed to achieving a ridge ratio of 1.09 due to the uniform size and shape of the layers. The reversible plough provided the smallest area occupied by clods bigger than 5 cm (0.16 m^2). Notably, fall-plowed soil disking, mineral fertilizers' incorporation, followed by soil rolling under rice with the BDM-'Agro' disk harrow and the Horsch Terrano 4 FX cultivator positively affected the structural and aggregate composition of the soil before rice planting. Using the Lemken Juwel 7 reversible plough and the Horsch Terrano 4 FX cultivator in the meadow-boggy soil treatment system contributed an average increase of 0.71 t/ha in rice yield under the environmental conditions of Kyzylorda Region, Kazakhstan. Employing these tillage units makes obtaining the maximum amount of agrotechnical soil fractions possible, positively affecting the field germination of seeds and rice grain yield.

Keywords: Rice, soil system, tillage equipment, structural and aggregate composition of soil, structural coefficient, tillage tools, yield

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Key findings: Results revealed the most effective field practice was autumn plowing with the reversible plow of the 'Lemken Juwel 7 type,' disk plowing and mineral fertilizers' incorporation, and rolling of the field with BDM-'Agro' and Horsch Terrano FX cultivators in the Aral Sea region, Kazakhstan, for all the studied variants for cultivating rice on meadow-marsh soils. These tillage units provided the maximum amount of agronomically valuable fractions in the surface layer of the ground, positively affecting rice seed germination and yield. However, other tillage methods considerably reduced agronomically beneficial segments.

INTRODUCTION

In Kazakhstan, the Kyzylorda region is the main rice-growing region, where the rice cultivation area is more than 250,000 hectares. In this area, rice as the principal crop reached cultivation in about 90,000 hectares, depending on available irrigation water. Within the last decade, the average rice grain yield has significantly increased from 4.25 to 5.34 t/ha. According to 2020 statistics, 86,200 tons of rice products worth USD 24.0 million became exports to nine countries, i.e., Russia, Kyrgyzstan, Belarus, Azerbaijan, Mongolia, Tajikistan, Ukraine, Turkmenistan, and Iraq (Akimat of Kyzylorda Region, 2023). It became possible, thanks to the selection of new highly productive adaptive varieties and their cultivation technology's improvement.

Grain yield increases due to the strengthening of rice production technologies; however, the cost of production does not decrease and amounts to an average of USD 157–162 per ton of crude rice for economic entities. In rice production systems, the labor costs are much higher than other crops cultivated through rotation and aimed at crop diversification (wheat, barley, soybeans, and sunflower). Therefore, for comparison, labor costs for the production of one ton of rice (averaged to 5–6 days) are much higher than for one ton of wheat production (1.2–1.5 days) (Udzukhu and Shashchenko, 2003).

The ultimate goal of the crop industry to obtain a higher yield depends upon several factors, such as soil condition, fertility, agrotechnical factors, and especially weather conditions (Karing *et al*., 1999). Proper crop production technology contributes to crop improvement and benefits all these factors - except for environmental factors (Zute *et al*., 2010). Soil properties' variations are a long-term prodigy, which depends on various factors (Mašek and Novák, 2018). The high costs of rice production correlate with low fertility and poor physical properties of paddy fields, and therefore, rice requires various types of tillage to create optimal conditions. In this regard, a significant part (about 20.9%–22.3%) of labor costs chipped in for basic and pre-sowing tillage operations (Grist, 1974).

Based on recommendations for carrying out spring-field works in the Kyzylorda Region, the pre-sowing tillage of the paddy field comprises several technological operations (Table 1). At the start of the fieldwork in the spring, autumn disking of the soil utilized the BDT-3 and BDT-7 in double-action in a 16–18 cm layer. After disking, the pre-sowing alignment continued using the planners D-719 or "Mara 50 MD" in a double action. Further, nitrogen and phosphatic fertilizers' incorporation followed in the soil to a depth of 8–10 cm with disc harrows BDT-3 and BDT-7. Nebytov (2005) showed that long-term agricultural use of the ground led to a depletion of available phosphorus in the arable layer. After applying mineral fertilizers and before sowing, the soil-rolling transpired using transverse rollers ZKKSH-6 type. Before sowing rice seeds, complete leveling of the field should end, and the soil should have a fine, cloddy structure.

Unlike the Krasnodar Krai, Russia, where mandatory post-sowing field rolling is necessary after rice sowing to evenly incorporate the seeds into the soil to a depth of 1.5 cm, in the Kyzylorda Region, Kazakhstan, this operation is inapplicable due to the high salinity of paddy fields (Nurgaliyev *et al*., 2015). As practice shows, excessive soil over-compaction contributes to drawing salts to the field surface, and washing them out of the

Table 1. Technological scheme of basic and pre-sowing tillage in the Kyzylorda Region (predecessor: rice by rice).

No.	Technological operations	Agricultural machinery and tools	Dates	Agrotechnical standards
	Basic tillage			
1	Fall moldboard plowing	Mounted, semi-mounted and trailing plows in the unit: PLN-5-35 + HTZ-150K; PLN-8-35 + K-701	September-October	To a depth of 27–30 cm (25–27 cm is allowed). Deviations from the specified depth – no more than ± 2 cm,
	Pre-planting cultivation			
2	Fall-plowed land disking	Disk harrows in the unit: BDT-3 + HTZ-150K; BDT-7+K-701	April	Processing depth 16–18 cm
3	Check plot surface layout	Laser planners in the unit: Mara 50MD+HTZ-150K, scraper D569+HTZ-150K	April	Surface alignment with ± 2–3 cm accuracy
4	Introduction of mineral fertilizers (50%–70% of the total nitrogen dose and 100% phosphorus)	Mineral fertilizer spreaders in the unit: RMG-3+MTZ-82; mounted Accord+MTZ-80; Amazon+MTZ-80	3rd decade of April-May	Uniform distribution of fertilizers on the check plot's surface
5	Mineral fertilizers incorporation	Disk harrows in the unit: BDT-3 + HTZ-150K; BDT-7+K-701	3rd decade of April-May	Uniform placement of fertilizers in 8–10 cm layer
6	Surface thinning with harrowing in double-action	Small spike-tooth harrows in the unit: BZTU-6+150K (thinning can be excluded when using a laser planner)	3rd decade of April-May	Complete destruction of lumps and equalization of the field
7	Pre-sowing soil packing	ZKKSH-6+MTZ-82	3rd decade of April-May	Complete destruction of lumps and equalization of the field

arable layer becomes difficult. According to the accepted rice cultivation technology, units pass through the field 9–11 times; all the techniques of pre-sowing soil cultivation are mainly machine-performing, and their use is not always reasonable, leading to an increase in energy and financial costs (Table 1). Therefore, using the recommended zonal technology for processing meadow-boggy soils, developed in 2011 under the conditions of a changing market in the rice-based crop rotation, does not allow the realization of vital activity factors of plants in the regional agricultural zone, as well as the potential yield of innovative rice cultivars approved for use (Zhumatayeva *et al*., 2017).

In modern conditions, with the arrival of dealer companies "Eurasia Group, Kazakhstan" and "ST AGRO" in the region, rice growing with traditional tillage machines began to acquire single-sided plows and reversible plow combined units. Thus, CT AGRO, established in 2000, is a large enterprise supplying and maintaining agricultural machinery in Kazakhstan. The ST AGRO has been a part of the Royal Reesink group in the Netherlands since 2014, with 13 branches. It also has operations in all Kazakhstan regions, including the Kyzylorda Region. It provides services for purchasing and maintaining high-performance agricultural machinery from manufacturers, i.e., CLAAS, HORSCH, and Valley.

The agrotechnical assessment issues of various foreign-made machines and implements during the soil's prime and pre-sowing tillage for rice cultivation in this region have no considerations. In this regard, establishing the effectiveness of using various new-generation tillage tools available to rice farms in this region is an urgent task for production and science. This research proposes to improve the soil cultivation system, ensure minimization of cultivation, gain optimal agrophysical properties of meadow-marsh soils, and increase rice yields in the natural conditions of the Kyzylorda Region of Kazakhstan.

MATERIALS AND METHODS

The Kyzylorda Region, located in the south of the Republic of Kazakhstan along the lower reaches of the Syrdarya River, occupies a large part of the Turanian lowland with a flat relief. In the west, it consists of the northern and eastern parts of the Aral Sea; in the south, the northern part of the Kyzylkum desert; and in the north, the Aral Karakum, Aryskum; and desert plateaus on the outskirts of Central Kazakhstan (Tokhetova *et al.,* 2020).

The experimental part of the relevant research on rice cultivation started in the Karaultyubinsk Base Station, Kazakh Scientific Research Institute of Rice Growing, named after I. Zhakhaev, located 10 km northeast of the Kyzylorda City, Kazakhstan (N44°51′10″/E65°30′33″) (Genievskaya *et al*., 2018). Conducting field research had a link to the rice-based crop rotation. According to the methodology of Kachinsky (1958), the mechanical composition of the experimental site's soil was heavily loamy, finely porous, and slightly cloddy. The granulometric constitution specifies the soil belongs to silty heavy loams and clays. Ground physical and technological properties, which also determine the water and air regimes, significantly impact the growth and development of rice plants. At the end of the growing season, the density of the arable soil layer of the experimental plot was 1.34 g/cm^3, with a slight increase in the underlying horizon (1.38 g/cm^3). High total porosity was evident in the more humidified upper horizons (56.1%) (Table 2).

The agrochemical properties of the experimental site indicate a low humus content (0.95%–0.84%) and a gradual decrease in its content down the profile. The arable layer's soil reaction increased (pH 7.8). In the study site's soil, the low content of organic substances also causes low-containing mobile and exchange forms of plant nutrition elements. Thus, the component of easily hydrolyzable nitrogen in the arable layer (0–20 cm) was 15.7 mg/kg of soil, mobile phosphorus was 15.3 mg/kg of soil, and the exchange potassium was 142.2 mg/kg of soil.

The experimental scheme, agricultural machinery, composition of tractors and tillage tools, and technological operations performed in the experiment are available in Table 3. The total area of the experimental plot was 10,800 m^2, the portion of one accounting plot was 600 m^2 (12 m × 50 m, the plot width was a multiple of the capture width of tillage tools), and their placement was systematic, with a fourfold repetition (Dospekhov, 1985). In addition to pre-sowing rolling for the region, using the rice cultivation's traditional technology was also simultaneous in the variants based on the recommendations for conducting spring fieldwork in the Kyzylorda Region. The seeding rate per hectare was 7.0 million viable or 700 germinating seeds/m^2 (250 kg/ha). Sown rice seeds with an Alpha SS-11.0 breeding seeder attained the constant-flooding irrigation mode. In the waxy ripeness phase, water from paddy fields reached complete discharge into the drainage and collector network. Rice mowing used a roller header while checking the 20%–25% soil moisture.

Determination of tillage quality

Soil density (g/cm^3) gained determination by the volume-weight method according to Kachinsky (1858), with the samples 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) by the pycnometer method. Determining the density of the treated soil layer was in five points at equal distances from each other along the diagonal of the plot. Determinations ensued before fall plowing and after pre-sowing rolling. Identifying soil hardness (g/cm^2) also continued before fall plowing and after pre-sowing rolling. Ridgeness (ridges' height) of the arable land surface capturing had the ridges' height measured using a bar and ruler after fall plowing. The height of all ridges from the base of the ridge to the scale attained measurement with a ruler on the field surface across the tillage direction along the entire width of the gripping unit. The acceptable height of the ridges was no more than 5–6 cm.

Table 2. Initial water-physical properties and agrochemical composition of meadow-boggy soils of the experimental site (average for 2019–2020).

Sampling depth (cm)	Humus (%)	Water-physical properties				Agrochemical composition			
		Specific gravity (g/c)	Soil density (g/cm^3)	Soil hardness (g/cm^2)	Porosity of the general layer (%)	Soil solution reaction (pH)	Mobile nitrogen (N) (mg/kg)	Mobile phosphorus (P2 O5) (mg/kg) (according to Machigin)	Exchangeable potassium (K_2O), (mg/kg) (according to Machigin)
0–20	0.95	2.61	1.34	5.4	56.1	7.8	15.7	15.3	142.2
20–40	0.91	2.63	1.38	11.2	51.4	7.7	13.9	14.1	120.0

Table 3. Agricultural machinery, the composition of tractors and tillage tools that performed the process/ operations in the variants of experiments.

1	Fall plowing to a depth of 25–27 cm			
	KhTZ-150K + PLN-5-35 *(control)*		ClaasAxion 820 + Lemken Juwel 7	
2	Disk fall plowing to a depth of 16–18 cm			
	KhTZ-150K + BDT-3 double-action *(control)*	KhTZ-150K + BDM-Agro	KhTZ-150K + BDT-3 in double-action	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
3	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 (urea) were applied fractionally, N_{60} kg/a.s. – before sowing, N_{60} kg/a.s. – in the tillering phase, phosphorus – in the form of basic superphosphate (with a phosphorus content of 20.0%). Calculated doses of mineral fertilizers were carried out considering the removal of nutrients with the harvest and utilization coefficients from the soil and fertilizers.

The cloddiness of the arable land's formation engaged the imposition of a 100 cm – 100 cm frame, with each 25 cm divided by a stretched wire. Then, considering the number of clods and lumps with a diameter of 6–10 cm and the portion occupied by them per m^2 of the frame ensued. The process continued with a five-fold repetition along the diagonal of the site. The allowed area under the clods was less than 15%–20%. On average, the plowing quality is considerably poor if there are more than five clods per m^2 of arable land. The soil structure determination used a set of sieves by dry scattering (by the method of I.I. Savinov). Using sieves with cell diameters 10, 7, 5, 3, 2, 1, 0.5, and 0.25 mm transpired by connecting them in a sequential set – from a larger diameter to a smaller one.

Phenological observations

During the rice growing season, the following observations proceeded. The water level measurement in the paddy fields used water gauges. Determining field germination and standing density of rice plants used a 0.25 m^2 frame by counting within the number of plants and rice stalks. The calculation was applicable in all experimental plots on seedlings and after rice harvesting. Phenological observations advanced following the Methodological Instructions (1982) on fixed sites in six-fold repetition with 25 plants. The onset of the phase considered its beginning in 10% of rice plants, and the mass in rice plants, 75%.

Meteorological conditions

The year 2019 has characteristics of higher temperatures than the average annual value. The average monthly air temperature during the active vegetation period (May-September) was 0.1 °C–3.9 °C higher than the long-term average (Table 5). In July, the hottest and driest weather of the summer period prevailed, and the average air temperature was +31.7 °C (Figures 1a, b). The maximum precipitation occurred from January to March (equal to 82.0 mm), which exceeds the norm by 33.0 mm (40.2%). However, the insignificant rainfall in September-October (6.0 mm) did not interfere with rice harvesting.

The year 2020 was also abnormally hot and mostly dry in summer. Temperature conditions also determined the timing (dates) of transitioning to the average daily air temperature through +10 °C compared with the long-term. The general increase in air temperature during this period contributed to soil warming to optimal temperatures and rice sowing 5–7 days (April 10–17) earlier than perennial terms. Noticeable deviations from long-term norms in terms of atmospheric precipitation were apparent for almost the entire calendar year.

Soil structure and its agronomic significance

Based on the particles' diameter, the soil structure incurred division into the following groups, i.e., cloddy (aggregates of more than 10 mm), macrostructure (10–0.25 mm), coarse microstructure (0.25–0.01 mm), and fine microstructure (less than 0.01 mm). Agronomically, the valuable structures considered aggregates have a diameter from 10 to 0.25 mm. The soil structure could be most useful when the specific gravity of agronomically valuable particles exceeds 55% in the soil. Aggregates larger than 10 mm had a cloddy formation and poor soil condition, just as the predominance of particles smaller than 0.25 mm occurred in the powdery part of soil aggregates. Therefore, utilizing the following qualitative assessments of soil structure continued based on the number of aggregates in this agronomically valuable range (10–0.25 mm).

RESULTS AND DISCUSSION

In Kyzylorda Region - Kazakhstan, rice farming is central on meadow-boggy soils, characterized by a low level of natural fertility, minimal humus (0.74%–1.55%), total nitrogen (0.084%–0.106%), and gross phosphorus (0.149%–0.171%) (Almerekova *et al*., 2019). Such soils with poor-quality tillage lead to deterioration of their agrophysical properties, which negatively affect the size and quality of the rice harvest.

The first observation of the experiments showed that when plowing with a one-sided plow (Lemken Juwel 7 reversible plough), the layers of meadow-boggy soils adjoin each other evenly and tightly, with the ridges clearly defined. Thus, due to the formation of layers of the same size and shape and their location from each other at the same distance, the coefficient of ridgeness in these areas was 1.05 (Figure 1a). This parameter was somewhat higher (1.15) in areas where plowing used a traditional plow PLN-5-35 (Table 4).

The results indicate that the number of clods (aggregates with a diameter > 5.0 cm) on the surface of the paddy field when plowing with a PLN-5-35 plow was 18.0 pcs/m^2, and the occupied area was 0.38 m^2. When processing with a one-sided Lemken Juwel 7 reversible plough, it was slightly less than 17.2 pcs/m^2. However, in this variant, the smallest area occupied by them was evident, and the cloddiness was consequently 0.16 m^2 (Figures 2a, b).

In general, the coefficient of ridgeness and the number of clods on the arable land surface largely depended not only on the physical condition of the soil but also on the design features of the compared plows. It should also be noteworthy that when using a single-sided plow, dividing the paddy fields into paddocks was no longer necessary, resulting in not having back furrows and back ridges.

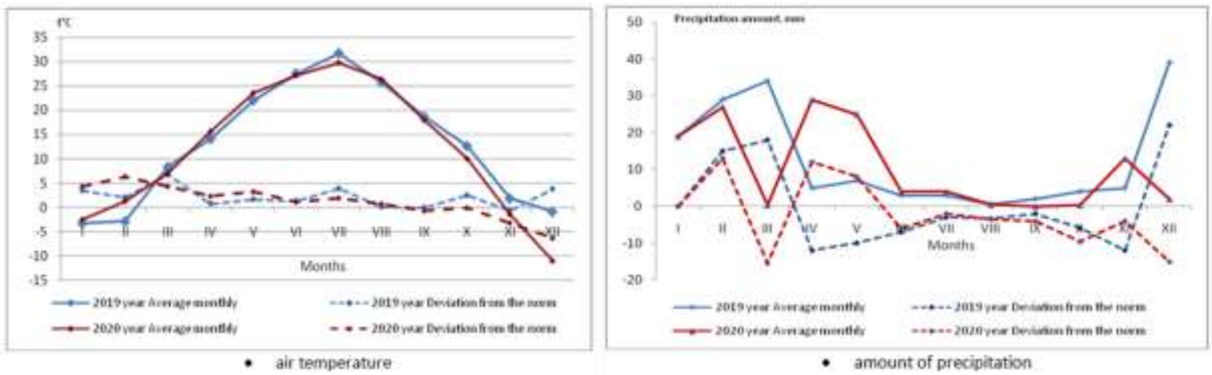

Figure 1. Meteorological indicators for years of research based on observations of the weather station, Kyzylorda City (2019–2020).

Table 4. Influence of various tillage tools on the ridgeness and cloddiness of meadow-boggy soils (average for 2019–2020).

Basic tillage to a depth of 25–27 cm	Ridgeness (cm)		Coefficient of ridgeness	Cloddiness (pcs/m^2)	Area under clods (m^2)
	length of the profile line	projection length*			
PLN-5-35	13.8	12.0	1.15	18.0	0.28
Lemken Juwel 7	12.6	12.0	1.05	17.2	0.16

Note: * - projection length is equal to the width of the accounting plot, i.e. 12.0 m.

A **B**

Figure 2. Fall plowing with Claas Axion 820+Lemken Juwel 7 unit; *a* – general view of the unit; *b* – determination of the field's cloddiness with a 1.0 m × 1.0 m accounting frame.

Table 5. Aggregate composition of the 0–10 cm soil layer after disking the 16–18 cm plow land layer with various tools (% by sample weight).

Fall plowing, processing depth 25–27 cm	Fall-plowed land disking, processing depth 16–18 cm (Factor)	Dimensions of aggregates (mm) and their content (%)					Structural coefficient
		>25	25-10	10-1	1-0.25	<0.25	
PLN-5-35	BDT-3 in double-action	30.5	37.5	27.8	5.3	0.9	0.49
PLN-5-35	BDM-"Agro"	22.3	35.2	30.8	9.6	1.1	0.67
Lemken Juwel-7	BDT-3 in double-action	25.8	36.4	30.6	8.4	0.8	0.63
Lemken Juwel-7	Horsch Terrano FX	18.2	32.6	33.6	11.7	1.9	0.82
HCP_{05}							0.03
t_{05}							2.18

Pre-sowing tillage

Disking the 16–18 cm layer of plow land with various tools started in the spring at the onset of physical soil ripeness (2nd week of April) on experimental plots tilled with PLN-5-35 and Lemken Juwel 7 plows. The results indicated that the studied tools had a different effect on the natural processes of structure formation and led to a change in the content of agronomically valuable aggregates with a diameter of 10 to 0.25 mm (Table 5).

The lowest content of agronomically valuable aggregates (33.1%) and a high content of the cloddy fraction (30.5%) appeared when using BDT-3 in double-action. It also follows from the table data that the use of combined tools, such as BDM-'Agro' and Horsch Terrano FX, leads to greater crumbling of the arable soil horizon, mixing of soil with plant residues, and increased formation of smaller soil particles. Thus, the share of cloddy aggregates (>10 mm) accounted for 6.2%–8.7% and fine-grained (19%–23%). Lemken Juwel 7 + Horsch Terrano FX composition dominated by a fraction of 3–5 mm.

The study results from a one-factor analysis of the soil structure coefficient after disking the layer was, i.e., 1st sign: P > 0.05, 5.06E-11 < 0.05, and the null hypothesis rejected; 2nd sign: F < Fcritical 244.5352 > 3.49029482, and the null hypothesis rejected. Thus, the influence of the experimental variants on the soil structure coefficient was significant. However, in these variants, a tendency to increase the structural coefficient persists due to an enhancement in the content of agronomically valuable particles and a decrease in the number of fractions with a size of <0.25.

By studying the physical soil properties in a 0–10 cm layer compared with the fall-plowed land disking with a processing depth of 16–18 cm (Table 7), significant variations in the structural and aggregate composition toward their improvement were visible under the different tillage tools' influence. Thus, in the control variant, when recommending the use of the BDT-3 disc harrow (application of nitrogen-phosphorus fertilizers) and the crosskill roller ZKKSH-6 as fine tillage, the percentage of agronomically valuable sizes was 50.7% (Table 6). In addition, a sharp differentiation between the cloddy (11.8%) and powdery fractions (2.1%) appeared in the control plot compared with other variants.

The soil treated with the BDM-'Agro' 3 x 4 disc harrow also revealed to contain 48.2% of soil particles (1 to 10.0 mm) in a 0–5 cm layer, and when treated with BDT-3 in double-action, soil particles were 48.7%. An explanation to this also referred to the action specifics of concave disks BDM-'Agro' on the soil structure and ground large lumps, and the slat-spiral rollers installed from the rear finally broke the soil into smooth chunks, leaving behind a perfectly smooth fluffed surface (Figures 3a, b). An impression also showed an increased number of agronomically valuable structural aggregates decreased the powdery fraction to 0.9% of the total aggregate amount when using the Horsch Terrano FX cultivator.

A one-factor analysis of the dispersion coefficient of the soil structure before sowing obtained the following results: 1st feature: P > 0.05; 1.9E-13 < 0.05, and the null hypothesis rejected; 2nd feature: F < Fcritical, 625,491 > 3,4902948, and the null hypothesis rejected. Thus, the influence of the experimental variants on the soil structure coefficient was significant. One of the reasons for the positive effects of the Horsch Terrano FX cultivator on the soil structure was the long-term presence of plowed soil in the working area and the unique shape of the racks, allowing for better mixing quality. In addition, when relying on the front hitch of the tractor and the compactor at the rear, this cultivator made it possible to strictly maintain the specified depth of applying mineral fertilizers (8–10 cm).

By cultivating the soil with the Horsch Terrano FX cultivator, 59.4% of the aggregate composition remained in the layer of surface 10 cm. After passing the BDT-3 disc harrows, most of these aggregates fell to the bottom of the furrow, and the hard-to-cut clods partially rose on the soil surface. In this regard, the upper layer contained more soil particles with a more than 25 mm diameter in the variants tilled with these tools. The structural coefficient of the 0–5 cm topsoil in all the variants, except for the control, ranged from 1.13 to 1.15. It

Table 6. Aggregate soil composition in a layer of 0–10 cm before sowing (% by sample weight).

Fall plowing, processing depth 25–27 cm	Fall-plowed land disking, processing depth 16–18 cm	Pre-sowing treatment, processing depth 8–10 cm	Dimensions of aggregates (mm) and their content (%)					Structural coefficient
			>25		10-1	1-0.25	<0.25	
PLN-5-35	BDT-3 in double-action control)	3+ZKKSH-6 (control)	11.8	37.4	36.6	14.1	2.1	1.02
PLN-5-35	BDM-‘Agro’	BDM-‘Agro’	6.8	38.4	42.6	10.5	1.7	1.13
Lemken Juwel 7	BDT-3 in double-action	BDT-3+ZKKSH-6	4.7	40.2	44.1	9.6	1.4	1.15
Lemken Juwel 7	Horsch Terrano FX	Horsch Terrano 4 FX	2.1	9.6	48.2	11.2	0.9	1.46
LSD_{05}								0.02
t_{05}								2.18

Table 7. The topsoil consistency density under rice (g/cm^3).

Fall plowing, processing depth 25–27 cm	Fall-plowed land disking, tilling depth 16–18 cm	Pre-sowing treatment, tilling depth 8–10 cm	Density of soil consistency in a 0–20 cm layer, g/cm^3	
			Before fall-plowed land disking	Before sowing
PLN-5-35	BDT-3 in double-action (control)	BDT-3+ZKKSH-6 (control)	1.26	1.30
PLN-5-35	BDM-‘Agro’	BDM-‘Agro’	1.26	1.28
Lemken Juwel 7	BDT-3 in double-action	BDT-3+ZKKSH-6	1.25	1.30
Lemken Juwel 7	Horsch Terrano FX	Horsch Terrano FX	1.25	1.27

A B

Figure 3. Nitrogen-phosphorus fertilizers' incorporation with the unit HTZ-150K + Horsch Terrano 4 FX: *a* –side view; *b* – rear view.

implies that the soil had better aggregate condition before sowing; the exception was the variant with a single-sided plow with a higher indicator (1.46). The content of agronomically valuable aggregates (0.25–10.0 mm) in the arable soil layer based on the variants was 55.3%–60.5%. First, it characterizes a good state of aggregation since the values were in the 40%–60% group, and secondly, no significant differences emerged between the tillage methods compared with the control variant (PLN-5-35).

The consistency density has a soil-zonal nature and depends on the content of organic substances in the soil, its granulometric composition, and its structure. Like other cultivated plants, rice grows and develops better at a constant density of the arable layer, ranging from 1.1 to 1.3 g/cm^3. Previously, Kandaurov *et al*. (1977) also revealed that the yield of rice decreases both on loose (<0.9 g/cm^3) and on dense (more than 1.3 g/cm^3) soil by 16%–32%. Also notable was the freezing of the soil plowed in autumn fall under the influence of winter weather conditions, contributing to its natural loosening. In this regard, by the beginning of spring pre-sowing treatments (2nd week of April), the soil density was relatively the same in all the experimental variants, amounting to 1.25–1.26 g/cm^3 (Table 7).

Furthermore, the study of topsoil density indicates that the reviewed tools and tillage methods had a different effect on soil density before rice sowing. Thus, the highest soil density in the 0–20 layer was evident on control plots when using traditional technology with serial tools (1.30 g/cm^3), while autumn soil disking of a 16–18 cm upper layer with the BDM-'Agro' disk harrow followed, with disking and rolling significantly reducing soil density by an average of 0.02 g/cm^3. The increase in density in the control variant was insignificant; its explanation refers to numerous coarse fractions available (Table 7), which had a loose consistency in combination. In the areas where autumn plowing transpired with a Lemken Juwel 7 reversible plough, the soil density of the upper 16–18 cm using BDT-3 disking and two tillage with the same tool after applying mineral fertilizers was 1.28 g/cm^3. The soil density was minimal in the variant with applied mineral fertilizers and had one rolled pass of Horsch Terrano FX– 1.27 g/cm^3. Thus, it should be well-defined that by the beginning of sowing, under the influence of meteorological conditions in the autumn-winter season, the soils under rice acquire optimal value despite the plows used in the settings of the Kyzylorda Region. Minimizing the pre-sowing treatment of meadow-boggy soils by combining disking and rolling in one technological process leads to a decrease in the 0–20 cm soil layer density by an average of 0.02–0.05 g/cm^3.

When preparing soil for sowing rice, it is necessary to account for the index of its hardness. High hardness worsens the physical-mechanical and agrophysical properties of the ground, hinders the germination of plants, prevents the development of their root system, and requires additional energy consumption during its cultivation (Herrick and Jones 2002; Lampurlanés and Cantero-Martinez, 2003; Zhapayev *et al*., 2023a, b).

When cultivating the soil of a rice field, its hardness is an essential indicator. High hardness shows a low supply level of soil with organic substances with the soil's physical, mechanical, and agrophysical properties deteriorating, the vital factors of plants will be insufficient for seed germination, and the root system will develop poorly, requiring additional energy costs. The results showed that before plowing and at the end of the rice growing season, all experimental variants incurred a slight increase in soil hardness with depth. After all the soil tillage, at the start of sowing rice, only a layer of 0–5 cm (4.0–4.3 kg/cm^2) remained uncompacted and deeper in the layer of 5–10 cm, the hardness value increased sharply compared with the initial state, having an average of 11.6–12.6 kg/cm^2 for all variants regardless of the tools used and the number of operations performed; in 10–20 cm layers it was 12.0–13.0 kg/cm^2, which was a good indicator for rice (Table 8).

Table 8. Soil hardness in various layers of the arable horizon under rice (kg/cm^2).

Fall plowing, processing depth 25–27 cm	Processing before sowing		Sample depth (cm)					
	Fall-plowed land disking, processing depth 16–18 cm	Disking, processing depth 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	BDT-3 in double-action (control)	BDT-3+ZKKSH-6 (control)	4.3	5.8	5.6	5.1	12.6	13.0
PLN-5-35	BDM-'Agro'	BDM-'Agro'	4.3	5.8	5.6	5.0	12.2	12.8
Lemken Juwel 7	BDT-3 in double-action	BDT-3+ZKKSH-6	4.0	5.6	5.6	4.8	11.8	12.1
Lemken Juwel 7	Horsch Terrano FX	Horsch Terrano FX	4.0	5.6	5.6	4.6	11.6	12.0

Thus, applying mineral fertilizers on meadow-swampy soils with subsequent soil rolling can attain complete replacement by modern tools BDM-'Agro' and Horsch Terrano FX. Throughout the rice-growing development in the Kyzylorda Region, a limited stable yield growth was due to low field germination of seeds associated with soil and climatic conditions, which does not exceed 30% (Zhumatayeva *et al*., 2017; Zhapayev *et al*., 2023a, b). In this connection, obtaining the optimal germination density (200–250 plants per m^2) requires developing an effective integrated tillage system.

The results disclosed that the aggregate soil composition significantly influences the rice plant's growth and development at the beginning of the growing season. The predominance of 1–10 mm fractions in the upper arable layer makes it possible to enhance rice seeds' germination, accelerate the emergence of seedlings, and develop favorable conditions for a sturdy root system. Therefore, according to Butov (1970), an increase in the proportion of the upper layer (0–5 cm) of aggregates from 1 to 10 mm in size contributed to a two-fold increase in field germination with the pre-sowing treatment. In this research, the first shoot of rice seeds appeared 5–7 days after sowing. As the initial data showed, tillage with various tools significantly impacted rice seed germination and their further growth and development. It also ensured better field conditions would positively affect seed germination (Table 9).

Against the background of fall plowing, where the processing proceeded with a plow PLN-5-35, the maximum field germination of rice seeds (218.2 pcs/m^2) came from the BDM-'Agro' disk harrow, and the smallest number (204.2 pcs/m^2) was from the control option, using the BDT-3 tool in double-action. The lower germination of rice seeds in this area can refer to the fact that in the paddy fields flooded with water, soil particles <0.25 mm coated the spores, and >10.0 mm covered the seeds after swelling. As a result, the rice seeds went under a layer of soil, burying a specific part of the formed seedlings.

From the given data, it can be visible that the maximum number of germinating rice seeds (223.8 pcs/m^2) emerged in the variant where plowing used a Lemken Juwel 7 reversible plough and fall-plowed land disking

Table 9. Field germination of seeds and plant preservation for rice harvesting depending on the tillage tools used (average for 2019–2020).

Fall plowing, processing depth 25–27 cm	Fall-plowed land disking, processing depths 16–18 cm	Pre-sowing treatment, tilling depth 8–10 cm*)*	Field germination		Plants' preservation for harvesting	
			pcs/m^2	%	pcs/m^2	%
PLN-5-35	BDT-3 in double-action	BDT-3+ZKKSH-6	204.2	30.6	135.7	66.5
PLN-5-35	BDM-'Agro'	BDM-'Agro'	218.2	31.1	142.7	65.4
Lemken Juwel 7	BDT-3 in double-action	BDT-3+ZKKSH-6	219.0	31.2	146.0	66.6
Lemken Juwel 7	Horsch Terrano FX	Horsch Terrano FX	223.8	31.9	150.0	67.0
LSD_{05}				0.7		1.3
$t_{0.5}$						2.18

Table 10. Rice grain yield during 2019–2020 depending on the tillage tools used (t/ha).

Fall plowing, processing depth 25–27 cm	Fall-plowed land disking, processing depth 16–18 cm	Pre-sowing treatment, tilling depth 8–10 cm	Grain yield (t/ha)	Control grain yield (t/ha)
PLN-5-35	BDT-3 in double-action	BDT-3+ZKKSH-6	6.12	-
PLN-5-35	BDM-'Agro'	BDM-'Agro'	6.54	+0.42
Lemken Juwel 7	BDT-3 in double-action	BDT-3+ZKKSH-6	6.32	+0.2
Lemken Juwel 7	Horsch Terrano FX	Horsch Terrano FX	6.83	+0.71
LSD_{05}			0.21	

and pre-sowing tilling with a Horsch Terrano FX cultivator, i.e., where the chief representation of the fractional composition in upper soil layer (in 0–5 cm) was by the size of aggregates (1 to 10 mm). The number of germinated plants in the Lemken Juwel 7 and BDT-3 variants was 219.0 pcs/m^2.

The one-factor analysis of the dispersion of the preservation of rice plants before harvesting obtained the following results: 1st sign: P > 0.05; 0.00059 < 0.05, and the null hypothesis rejected; 2nd sign: F < Fcritical, 12.2 > 3.49029482, and the null hypothesis rejected. Thus, the experimental variants' influence on the safety of rice plants was significant. The analysis showed that the rice yield in all experiments was generally higher throughout all the years of research. The results confirmed the effectiveness of using the 'Lemken Juwel 7 reversible plough' plow in conjunction with the Horsch Terrano FX cultivator, where it provided the highest rice yield (6.83 t/ha), with a yield increase of 0.71 t/ha compared with the control variant (Table 10). It was primarily due to more optimal agrophysical properties, a high coefficient of soil structure (1.46) before sowing rice, and the higher rice seeds' germination in the studied variant.

The results obtained with a one-factor analysis of rice grain yield were: 1st sign: P > 0.05; 2.36E-11 < 0.05 and the null hypothesis rejected; 2nd sign: F < Fcritical, 278.275 > 3.49029482 and the null hypothesis rejected. In conclusion, the experimental variants' impact on the yield of rice grains was significant. Accounting for the rice harvest in the variant using the traditional plow PLN-5-35 and the BDM-'Agro' disk harrow for fall-plowed land disking and application of mineral fertilizers with subsequent pre-sow rolling of the field also contributed to an increased rice yield (0.42 t/ha).

CONCLUSIONS

In ensuring optimal agrophysical properties of meadow-boggy soils and obtaining consistently high rice grain yield in the conditions of the Kyzylorda Region, Kazakhstan, it is advisable to carry out autumn plowing with a reversible plow of the Lemken Juwel 7 type, as well as, autumn soil disking and mineral fertilizers' incorporation with simultaneous rolling of the field surface with the BDM-'Agro' disk harrows or Horsch Terrano FX cultivators.

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