NECESSITY AND POSSIBLE APPROACHES TO APPLYING DEEP LOOSENING WHEN CULTIVATING RICE
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НЕОБХІДНІСТЬ ТА МОЖЛИВІ ПІДХОДИ ДО ЗАСТОСУВАННЯ ГЛИБОКОГО РОЗПУШЕННЯ ПРИ ВИРОЩУВАННІ РИСУ

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ABSTRACT

It is ascertained that the issue of ecological rational use of water and land resources in the cultivation of rice determines the need for differentiation of the degree of soil drainage, which involves the direction and intensity of soil processes. It is substantiated that one of the expedient measures is the deep loosening of rice field's soils. Possible approaches to improving, constructing and implementing effective deep loosening tools are suggested. Research and production research was carried out on the basis of Liskovsky rice irrigation system in the Odessa region (Ukraine), the soil conditions of which are typical for most of the Danube rice irrigation systems. It is substantiated that a most effective measure in the cultivation of rice is the implementation of a continuous deep loosening by a long-range deep-thrower of a new type, the application of which reduces the density and increases the permeability of the soil, respectively, by 1.26 and 4.45 times. Due to the corresponding structure of loose soil, this leads to a significant improvement of the water-physical properties of the soils, increasing their filtration capacity throughout the area of fields in grown rice, increasing the accumulation capacity of the aeration zone for the accompanying crops.

РЕЗЮМЕ

Визначено, що питання екологічного раціонального використання водних і земельних ресурсів при вирощуванні рису визначає необхідність диференціації ступеня дренованості ґрунту, з яким пов'язана направленість і інтенсивність ґрунтових процесів. Визначено, що одним з доцільних заходів при цьому є глибоке розпушення ґрунтів рисових чеків. Запропоновано можливі підходи щодо удосконалення та застосування ефективних засобів глибокого розпушення. Дослідно-виробничі дослідження було виконано на базі Лісковської рисової зрошувальної системи в Одеській області (Україна), ґрунтові умови якої є характерними для більшості Придунайських рисових зрошувальних систем. Обґрунтовано, що найбільш ефективним заходом при вирощуванні рису є здійснення суцільного глибокого розпушення ярусним глибокорозпушувачем нового типу, застосування якого через зменшення щільності та збільшення водопроникності ґрунту, відповідно, в 1,26 і 4,45 рази, за рахунок відповідної структури розпушеного ґрунту, призводить до суттєвого покращення водно-фізичних властивостей ґрунтів, підвищення їх фільтраційної здатності за всією площею чеків при вирощувані рису, підвищення акумулюючої здатності зони аерації для супутніх культур.

INTRODUCTION

In the modern world, environmental problems are becoming increasingly acute due to intensive man-made use of water and land resources (*Hamzaa M.A., Anderson W.K., 2005, Iglesias A., Garrote L., 2015, Ward P.R., Flower K.C., Cordingley N. and others, 2012*). In particular, this applies to the environmentally sound use of water and land resources of rice irrigation systems (RIS).

The ecological-improvement state of RIS is determined by a number of factors, the main ones being natural (climatic) and technological. The most significant influence on the ecological and improvement state of the RIS is carried out by groundwater, the regime of which in rice systems is determined by the intensity and direction of filtration processes occurring in the course of prolonged excessive moisture of soils and leads to a decrease in their fertility. (*Shunsaku Nishiuchi, Takaki Yamauchi and others, 2012, Stashuk V.A., Rokochynskyi A.M. and others, 2016, Ward P.R., Flower K.C., Cordingley N and others, 2012*).

With modern changes in climatic conditions, in particular, with changes in the number and timing of precipitation, temperature conditions, it is necessary to modify the implementation of existing technologies of water regeneration of fertile soils RIS (*Iglesias A., Garrote L., 2015, Shunsaku Nishiuchi, Takaki Yamauchi and others, 2012*).

The study and analysis of research data at the Danube RIS in the Odessa region during the 50 years since the 60s of the last century enabled to identify some technological disadvantages in the rice cultivation. Studies have shown that the most favourable salt, temperature and water-air regime is created only along drainage and discharge canals. In a 50 m wide strip along irrigation channels of different order, there is an outflow of groundwater, the temperature of which is lower, and the mineralization is much higher than the irrigation water. This leads to a deterioration of the temperature and salt regime of the upper horizons of soils and, consequently, to a decrease by 5 ... 10%, and in saline lands up to 30% of rice yield as the leading crop. Similar conditions are created in a strip of 30 m wide in the lower field, if the field mark next to it is higher by 0.3 ... 0.6 m. The yield of rice in this strip is 10 ... 30% lower than the average one by field (Fig. 1) (*Stashuk V.A., Rokochynskyi A.M. and others, 2016*).

Active filtering when flooding a field takes place only on the smaller part of the area (about 1/3), which adjoins directly to the drainage and discharge canal. The size of the groundwater outflow zone is about 10-15 m, the active filtration zone is 20 ... 30 m, the rest of the rice field (60 ... 160 m) is a stagnant zone. The yield of rice in a strip with a small filtration is 25 ... 35% lower than the average on a field (Fig. 2) (*Stashuk V.A., Rokochynskyi A.M. and others, 2016*).

This necessitates the improvement of its design in order to increase drainage capacity over the area of the rice field and the soil profile.

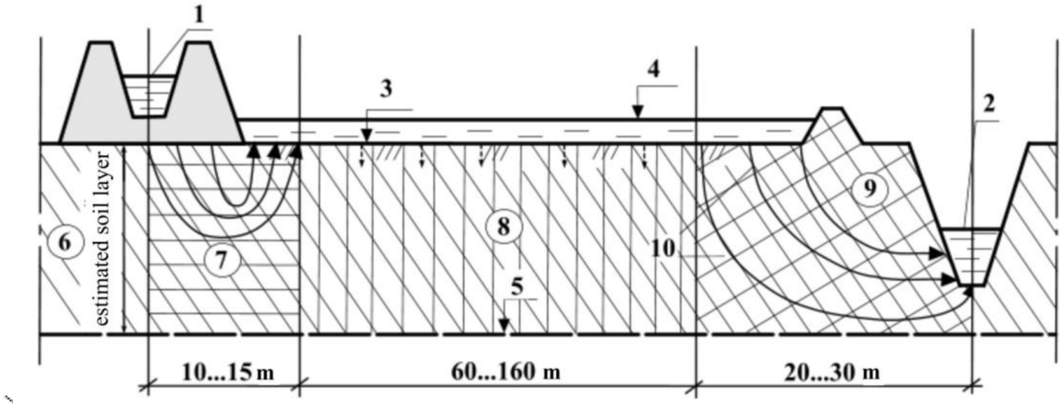


Fig. 1. Scheme of forming characteristic filtration zones on the profile of a rice field:
1 – field's irrigation canal; 2 – field's drainage and discharge canal; 3 − soil surface; 4 − water surface; 5 − boundary of the estimated soil layer; 6 − estimated soil layer; 7 − zone of groundwater outflow; 8 − stagnant zone; 9 − active filtration zone; 10 − filtration streams movement direction lines.

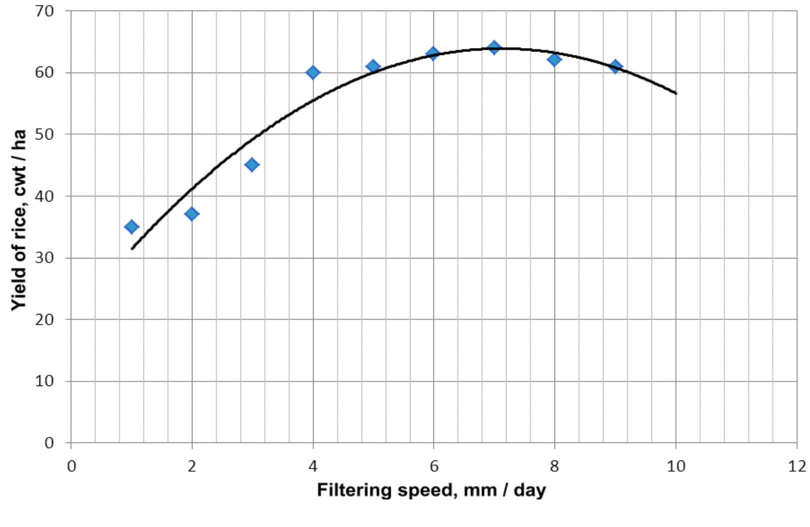


Fig. 2 - Dependence of the rice yield on the rate of filtration from the field's surface during the vegetative season

In conditions of rice systems, increasing the filtering of rice fields may be achieved by arranging a systematic internal closed drainage. This measure is quite effective, but its implementation requires significant investments. Therefore, taking into account the current market conditions, there is a need to find alternative and more economical ways of solving this issue.

One of the most effective measures to increase drainage on the RIS can be the deep loosening of the soil of rice fields.

Execution of deep loosening of the cover layer of soil, which in the conditions of RIS is practically water resistance (*Hamzaa M.A., Anderson W.K., 2005*), will affect the change of its water and physical characteristics, will increase its water permeability, the uniformity of filtration in the area of the field, the accumulation of moisture in the cultivation of related crops.

The technology of deep loosening can be slit, striped and solid. Depending on the principle of action and design features, deep-rippers are divided into two groups: active and passive working equipment (*Pyvovar V., 2011*).

In practice, widespread passive deep-rippers were acquired. They are reliable, simple in design and in operation, but require more powerful tractors (*Kravets S.V., Skobluk M.P. and others, 2018, Mikchail Laziuta, Bajan Kabulova, Chalit Gasanov, 2013*).

In many countries, tools that are very simple in design and reliable in operation, including a frame on the support wheels with several ripping or slit-cutting working elements installed on it are used for deep loosening. The working element of the deep loosening device consists of a straight or curved support, on which a flat or shaped chisel is attached. To increase the loosening area, additional expanders are fixed on the supports (*Kravets S.V., Skobluk M.P. and others, 2018, Gavrysh V.S., Tkachuk V.F. and others, 2013*).

The traditional support pattern deep loosening devices (of type RU-45, RG-0.8A, RNT 0.8A, and others) and their contemporary counterparts do not fully meet the quality criteria for loosening without applying additional soil cultivation due to their design features. The main disadvantage of such deep loosening means is the lack of the guided differentiation of the soil loosening quality in depth, which is very important for obtaining a favourable water-physical state of the soil (*Rokochynskyi A.M. Lukyanchuk O.P. and others, 2017; Rokochynskyi A.M., Lukyanchuk O.P., Volk P.P., 2017, Rokochynskyi A.M., Stashuk V.A. and others, 2011*).

A more progressive in this regard is the construction of a multistage loosening device of a new type (*Tkachuk V.F., Lukyanchuk O.P., Ryzhyi O.P., 2011; Lukyanchuk O.P., Ryzhyi O.P., Ihnatiuk R.M., 2017*) (Fig. 4). This technical solution enables to purposefully influence the structure of the soil in each developed horizon and differentiate the degree of its loosening in depth (*Tkachuk V.F., Lukianchuk O.P., Ryzhyi O.P., 2011*).

It is necessary to determine the rational type of deep loosening and technical means of its implementation due to their influence on the filtration and physical characteristics of the soil RIS.

MATERIAL AND METHODS

Research and production research was carried out on the basis of Liskovsky RIS in the Odessa region (Ukraine). Soil conditions are characteristic of most of the Danube RIS (Table 1).

Table 1

The averaged water-physical properties of the soils of Liskovsky RIS

Soil layer, m	Density, t /m^3	Porosity, %	Water permeability, m/day
0…0.2	1.42	46.8	0.13
0.2…0.4	1.45	45.3	0.03
0.4…0.6	1.34	50.9	0.16
0.6…0.8	1.58	43.8	0.12

The permeability of the cover layer of soils (0 ... 60 cm) is quite low and ranges from 0.008 to 0.02 m / day. The top layer, 0.4 ... 0.6 m thick, is the most dense, represented by loams, and below it is a thin (0.3 ... 0.4 m) layer of sandstone. Still below is the sand, which includes a significant amount of dusty fractions, ranging from 1 to 2 m. The sand gradually becomes sandy loam, under which there is a dusty loam which is waterproof.

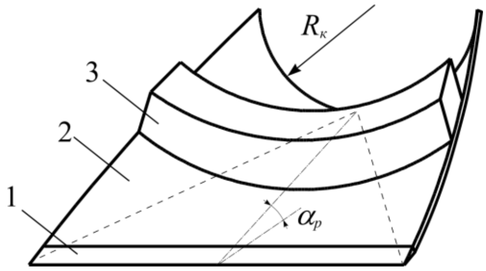
Study of various technologies and means of deep loosening on water-physical properties of soils and land improvement status and operation of the existing drainage system in general, conducted to the following options:

1 - slit loosening to a depth of 0.6 m with two-tier deep-ripper type RU -45;
2 - strip loosening to a depth of 0.6 m three-tier deep-ripper of a new type with one riser in each tier (Fig. 3);
3 - solid loosening to a depth of 0.6 m two-tier deep-ripper of a new type with three risers in each tier (Fig. 3);
4 - control version without loosening.

The experimental sites were placed in the form of a "Latin square".

The operational equipment of a new type of deep-thrower consists of a frame with variable risers (1 ... 3 pcs in each tier), on which the loosening elements are fixed in the form of the conjugation of the horizontal knife (cutter) with the concave symmetric surface of the variable curvature (Tkachuk V.F., Lukianchuk O.P., 2014). Due to the shape and parameters of this surface, the required deformation together with the degree of stress are assigned, and, consequently, the crushing of the developed layer of soil (Fig. 3) (*Kravets S.V, Kovan'ko V.V., Lukianchuk O.P., 2015; Lukianchuk O.P., Ryzhyi O.P., Ihnatiuk R.M., 2017*).

a)



b)

Fig. 3. Multi-level deep-ripper for strip and continuous loosening:
a) − a two-tier working equipment; b) − the soil loosening surface: 1 - horizontal knife (cutter), 2 - soil loosening surface, 3 - element of soil chips, $R_к$ − the radius of the end surface curvature, α_p − installation angle.

The choice of a multi-tier deep-ripper of a new type is due to the following. As the practice and acquired agricultural production experience show, the vertical soil profile of the farmland should have an anti-erosion top layer (0 ... 0.05 m), a roots-like layer (0.05 ... 0.4 m) and a lower filtration layer (> 0.4 ... 0.6 m). At the same time, the structure of the soil (percentages by weight of groups of "valuable" and other sizes) of each of these layers should be optimal in accordance with the purpose of each of them (*Gavrysh V.S., Tkachuk V.F. and others, 2013*).

After having been loosened by such a working element, the soil structure is determined by a number of the soil mass grinding stages on the soil loosening surface, and their number, in turn, depends on the value of the surface curvature of each tier (*Tkachuk V.F., Lukianchuk O.P., Melnyk A.V., 2008, Tkachuk V.F., Lukianchuk O.P., Ryzhyi O.P., 2011*). Therefore, it is advisable to make the working equipment of the deep-ripper of 2 ... 4-tier.

In order to determine the working parameters of the new type of deep-throwing loose elements through analytical research, the differentiation and composition of the soil structure in each developed layer was determined and evaluated based on the averaged soil aggregate of loose soil and multiplicity of crushing.

RESULTS

The soil extraction elements with different working parameters have different values of the average soil aggregate and the multiplicity of soil crushing (Table 2, Fig. 4).

Surfaces with various defining parameters have different values of the averaged soil aggregate and the grinding multiplicity of the soil mass. If the value of the averaged soil aggregate has a nearly proportional dependence on the depth of development in the layer and the end radius, then the magnitude of the grinding multiplicity has a rather complex dependence. This difference is due to the fact that the magnitude of the crushing multiplicity is influenced by the width of the soil loosening surface, the value of which, in the calculation, is variable. It does not affect the magnitude of the formed aggregates. The most effective soil crushing, taking into account the size of the averaged soil aggregate, occurs at a depth of 150 mm and an end radius of 150 mm, and the least effective − at a development depth of 150 mm and an end radius of 200 mm.

Table 3

Results of the soil grinding structure analytical study

Initial parameters		Structure of loosened soil, $l_к$							Grinding multiplicity of the soil initial volume
Tier height, $h_к$, mm	End radius of the surface, $R_к$, mm	Dimensions of formed soil aggregates	<5 mm	5–10 mm	10–25 mm	25–50 mm	>50 mm	Averaged soil aggregate, mm	
100	150	Pcs,%	41.07	24.85	24.12	7.37	2.59	4.92	973
		Capacity,%	2.59	4.28	18.76	33.30	41.07		
	200	Pcs,%	23.37	32.31	31.37	9.59	3.37	5.58	1009
		Capacity,%	1.47	4.33	18.98	33.68	41.54		
	250	Pcs,%	0.00	42.16	40.94	12.51	4.39	6.33	981
		Capacity,%	0.00	4.39	19.26	34.19	42.16		
150	150	Pcs,%	40.44	32.79	15.43	7.26	4.09	5.74	1072
		Capacity,%	1.54	4.39	9.33	19.83	64.90		
	200	Pcs,%	0.00	55.05	25.90	12.19	6.87	7.38	865
		Capacity,%	0.00	4.46	9.48	20.14	65.92		
	250	Pcs,%	0.00	55.05	25.90	12.19	6.87	7.38	1081
		Capacity,%	0.00	4.46	9.48	20.14	65.92		
200	150	Pcs,%	40.23	32.62	15.35	7.22	4.59	6.75	1034
		Capacity,%	1.19	3.40	7.22	15.35	72.84		
	200	Pcs,%	22.75	42.15	19.83	9.33	5.93	7.65	1072
		Capacity,%	0.67	3.42	7.26	15.43	73.23		
	250	Pcs,%	0.00	54.57	25.67	12.08	7.68	8.68	1043
		Capacity,%	0.00	3.44	7.31	15.53	73.72		

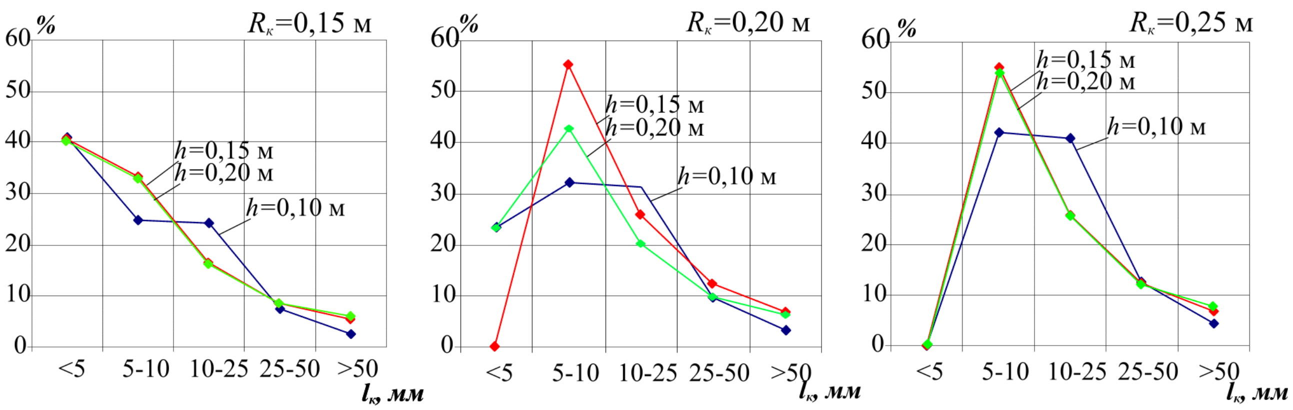


Fig. 4. The structure of loose soil by the number of soil aggregates

$h_к$ - tier height, mm; $R_к$ - the radius of the end surface curvature, mm; $l_к$ - soil aggregates, mm

From fig. 4, it results that in order to loosen the anti-erosion top layer (0 ... 0.05 m), it is expedient to use working surfaces with a finite radius of about 200 mm, for a roots-containing layer (0.05 ... 0.4 m) with a finite radius of about 150 mm, for the lower filtration layers (> 0.4 ... 0.6 m) with a finite radius of about 250 mm.

A generalized comparative characteristic of the main indicators values of water and physical properties in a 0.6 m layer of rice systems irrigated soils depending on different types and variants of their loosening and averaged in time (after the effect term) and space (by the soil profile) are given in Table 3.

Table 3

Comparative characteristic of water and physical properties of 0.6 m soil layer in terms of loosening variants

Indicators / Variants of loosening	Density, t /m^3			Porosity, %			Water permeability, m/day		
	abs value	Deviation from control		abs value.	Deviation from control		abs value.	Deviation from control	
		t /m^3	%		t /m^3	%		t /m^3	%
Without loosening (control)	1.45	–	–	42.2	–	–	0.12	–	–
Slit loosening	1.41	0.04	2.9	46.1	3.9	9.2	0.25	0.13	206
Strip loosening	1.32	0.13	8.9	47.3	5.1	12	0.36	0.24	296
Continuous loosening	1.15	0.30	21	54.9	12.7	30	0.53	0.41	443

For all types of loosening there was decreased density and increased permeability. The most effective in this regard was the continuous loosening, with density and permeability changed by 1.26 and 4.45 times respectively.

The results of the experiment were introduced into previously obtained mathematical models of crop yield dependence on ground conditions characteristics (*Stashuk V.A., Rokochynskyi A.M. and others, 2016*). By means of machine experiment, predicted values of crop yields of rice crop rotation for several years with different variants of deep loosening are shown in Table 4.

Table 4

Estimated crop yields of rice crop rotation in terms of loosening variants

No b/o	Loosening variants	Crops	Crop yields in estimated years,%					Predicted crop yields, cwt/ha
			10	30	50	70	90	
1	Without loosening (control)	Rice	32.0	34.0	36.0	38.0	40.0	35.9
		Perennial grasses	240.0	220.0	210.0	180.0	160.0	203.0
		Winter cereals	38.0	36.0	32.0	28.0	26.0	31.9
		Rape	20.0	28.0	34.0	36.0	38.0	32.0
		Vegetables	280.0	300.0	340.0	360.0	400.0	339.0
2	Slit loosening	Rice	40.0	52.0	58.0	62.0	64.0	56.0
		Perennial grasses	270.0	250.0	260.0	210.0	190.0	233.0
		Winter cereals	43.5	41.5	37.5	33.5	31.5	36.5
		Rape	24.0	32.0	38.0	40.0	42.0	36.0
		Vegetables	320.0	340.0	380.0	400.0	440.0	379.0
3	Strip loosening	Rice	45.0	57.0	63.0	67.0	69.0	61.0
		Perennial grasses	280.0	260.0	270.0	220.0	200.0	243.0
		Winter cereals	47.5	45.5	41.5	37.5	35.5	40.5
		Rape	29.0	37.0	43.0	45.0	47.0	41.0
		Vegetables	360.0	380.0	420.0	440.0	480.0	419.0
4	Continuous loosening	Rice	49.0	61.0	67.0	71.0	73.0	65.0
		Perennial grasses	295.0	275.0	285.0	235.0	215.0	243.0
		Winter cereals	50.5	48.5	44.5	40.5	38.5	43.5
		Rape	33.0	40.0	47.0	49.0	51.0	45.0
		Vegetables	390.0	420.0	450.0	470.0	510.0	449.0

According to the results presented, the application of deep loosening provides the following increase in crop yields: slit − 5...10%; strip − 10…20%; continuous − 20...40%.

The results presented in relation to the predicted values of rice crop rotation, crop yields adequately reflect the achieved degree of improving conditions of plants cultivation in terms of the variants of rice systems soils deep loosening.

The obtained results and their dynamics are in good agreement with the results obtained earlier from similar 3-year studies of field trials for various technologies and means of deep loosening on the reclaimed lands of the experimental sites "Uyizdtsi" and "Pechalivka" in the Rivne region (Ukraine) (Gavrysh V.S., Tkachuk V.F. and others, 2013, Rokochynskyi A.M., Lukianchuk O.P. and others, 2017).

CONCLUSIONS

Deep loosening is one of the expedient alternative measures for increasing the efficiency of RIS. It has a positive effect on the increase in yield due to improving the water-physical properties of irrigated soils, increasing their overall moisture content by increasing the accumulation capacity of loose soil.

In the rice field, deep loosening provides the required uniformity and intensity of filtration, ensures uniform filtration by area and profile, and enhances the drainage of the rice field as a whole.

In periods of overflow, deep loosening contributes to accelerated release of the arable layer from excess moisture during rice cultivation, accelerating its movement in the lower layers, and in the dry season deep loosening contributes to the accumulation of moisture due to the high accumulation capacity of loosened soil.

The effectiveness of the drainage system improves and the opportunity to increase the distance between the drains increases, which in turn enables to reduce the specific investments in the RIS construction and reconstruction projects.

The investigated technologies and deep loosening means of rice systems irrigated soils mainly have a positive effect on the change of soil water-physical properties, moisture content during vegetation periods and crop depending on the type of cultivated crops.

In general, the most effective measure for rice cultivation is the implementation of a continuous deep loosening by a new type of deep-ripper, the use of which, due to a decrease in the density and increase in permeability of the soil, respectively, by 1.26 and 4.45 times, due to the corresponding structure of loose soil, leads to significant improvement of soil water-physical properties, increase their filtration ability throughout the area of fields in grown rice, increase the accumulation capacity of the aeration zone for the accompanying crops.

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