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# АГРОФИЗИЧЕСКИЕ И АГРОХИМИЧЕСКИЕ СВОЙСТВА ТЕМНО-СЕРЫХ ЛЕСНЫХ ПОЧВ ПРИ РАЗЛИЧНЫХ СИСТЕМАХ ОСНОВНОЙ ОБРАБОТКИ

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Определено влияние продолжительного использования различных систем основной обработки темно-серой лесной почвы на агрофизические свойства, питательный режим и урожайность зерновых в зернопаровых севооборотах. Исследования проведены в условиях Северного Зауралья в стационарном опыте в 1996–2018 гг. Изучены традиционная отвальная и ресурсосберегающие системы основной обработки почвы. Опыт проходил в течение 3–6-й ротации двух зернопаровых севооборотов, развернутых во времени и в пространстве: чистый пар – озимая рожь – яровая пшеница – яровая вика – яровой ячмень; чистый пар – озимая рожь – яровая пшеница – яровая пшеница – яровой ячмень. При возделывании зерновой культуры, завершающей зернопаровой севооборот, в четвертом поле после пара по зернобобовому предшественнику (яровой вике) целесообразно применение систем основной обработки почвы с элементами минимизации. К ним относятся безотвальная и комбинированная системы с безотвальным рыхлением плугом со стойками СибИМЭ на 20–22 см; дифференцированная с плоскорезной обработкой на 12–14 см и дискование на 10–12 см. Изучаемые системы обработки обеспечивали близкие отвальной системе условия водного режима, сложения почвы и пищевого режима. Сформирована практически равная отвальной системе урожайность ячменя: на фоне естественного плодородия – 2,97–3,03 т/га, с применением $N_{40}P_{40}P_{40}$ – 3,47–3,65 т/га. Применение систем обработки с элементами минимизации в зернопаровом севообороте без наличия зернобобовой культуры под данную культуру по повторной зерновой культуре (пшенице) приводило к следующим результатам. Обеспеченность продуктивной влагой в слое почвы 0–1,0 м снизилась на 8,6–28,0%, значительно ухудшился пищевой режим, в особенности азотный (на 15,5–43,8%) и фосфорный (на 39,1–51,1%), с отрицательной дифференциацией плодородия почвенного профиля, урожайность зерна снизилась на 0,09–0,40 т/га.

**Ключевые слова:** система основной обработки, севооборот, предшественник, элементы плодородия, яровой ячмень, урожайность, эффективность производства

# AGROPHYSICAL AND AGROCHEMICAL PROPERTIES OF DARK GREY FOREST SOILS UNDER DIFFERENT SYSTEMS OF BASIC TILLAGE

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The effect of long-term use of different systems of basic tillage of dark grey forest soils on the agrophysical properties, nutrient regime and yield of grain crops in grain-fallow crop rotations was determined. The study was carried out in the conditions of the Northern Trans-Urals in a stationary experiment in 1996–2018. The traditional moldboard and resource-saving systems of basic tillage were studied. The experiment took place during the third–sixth rotations of two grain-fallow crop rotations spread in time and space: bare fallow – winter rye – spring wheat – spring vetch – spring barley; bare fallow – winter rye – spring wheat – spring wheat – spring barley. When cultivating a grain crop that completes a grain-fallow crop rotation, in the fourth field after the fallow with a legume forecrop (spring vetch), it is advisable to use systems of basic tillage with elements of minimization. These include non-moldboard and combined tillage with subsurface loosening by a plow with SibIME tines to a depth of 20–22 cm differentiated with stubble-mulch at 12–14 cm and disk harrowing at 10–12 cm. The studied tillage systems ensured the conditions of the water regime, soil composition and nutritional regime close to the moldboard tillage system. The yield of barley almost equal to the moldboard system was formed: against the background of natural land fertility – 2.97–3.03 t/ha, with the use of $N_{40}P_{40}P_{40}$ – 3.47–3.65 t/ha. Application of tillage systems with minimization elements in a grain-fallow crop rotation without planting a leguminous crop with a given crop for a repeated grain crop (wheat) led to the following results. Productive moisture availability in the soil layer 0–1.0 m decreased by 8.6–28.0%, the nutrient regime worsened significantly, especially nitrogen (by 15.5–43.8%) and phosphorus (by 39.1–51.1%), with the negative differentiation of soil fertility, and reduction of grain yield by 0.09–0.40 t/ha.

**Keywords:** system of basic tillage, crop rotation, forecrop, fertility elements, spring barley, yield, production efficiency.

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## INTRODUCTION

In the Northern Trans-Urals, as well as in other regions of the country, in field cultivation there is an increasing use of less expensive methods of cultivation than ploughing, using non-moldboard, flat-cut processing and disking in basic cultivation. This is due to economic reasons, the possibility of increasing productivity and reducing fuel costs. However, scientific studies on this topic in the region and abroad do not give an unambiguous answer about the influence of technologies of different intensity on the elements of soil fertility, as well as about their comparative efficiency in comparison with traditional plowing [1-3]. At the same time, it is important to establish the peculiarities of the influence of cultivation systems on soil fertility during the cultivation of cereals in crop rotations with precursors of different biology [4–6].

The aim of the study is to determine the effect of long-term use of various systems of the main processing of dark gray forest soil in the conditions of the Northern Trans-Urals on agrophysical properties, nutritional regime and yield when cultivating a grain crop grain using forecrop (spring wheat) and leguminous (vetch for grain) predecessors.

## MATERIALS AND METHODS

The studies were carried out in 1996–2018 in the stationary experiment of the Scientific Research Institute of Agriculture of the Northern Trans-Urals - a branch of the Tyumen Scientific Center of the SB RAS. The experiment took place during the period of the 3rd-6th rotations of two grain-fallow crop rotations, deployed in time and space: pure fallow - winter rye - spring wheat - legumes (spring vetch for grain) - spring barley; pure fallow - winter rye - spring wheat - spring wheat - spring barley. Observations and counts were carried out in a barley field. The studied soil cultivation systems are presented in table 1. Techniques of the main processing were performed after harvesting the crops.

Pre-sowing treatment for all studied systems of the main treatment consisted in early spring harrowing with BZSS-1.0 tooth harrows in pre-sowing cultivation with the Smaragd-6 cultivator to the depth of seeding. Sowing was carried

**Табл. 1.** Системы обработки почвы
**Table 1.** Soil tillage systems

| Soil tillage system | Tillage methods after harvesting crops | | | | |
|---|---|---|---|---|---|
| | Steam | Winter rye | Wheat | Grain legumes / wheat | Barley |
| Mouldboard | Plowing with a Lemken plow to a depth of 20-22 cm | | | | |
| Non-mouldboard | Loosening with SibIME tines to a depth of 20-22 cm | | | | |
| Combined | Lemken to a depth of 20-22 cm | SibIME tines to a depth of 20-22 cm | Lemken to a depth of 20-22 cm | SibIME tines to a depth of 20-22 cm | Lemken to a depth of 20-22 cm |
| Differentiated | Smaragd cultivator to a depth of 12–14 cm | Smaragd cultivator to a depth of 12–14 cm | Lemken to a depth of 20-22 cm | BDT-2,5 to a depth of 10–12 cm | BDT-2,5 to a depth of 10–12 cm |
| Flat-cut | Smaragd cultivation to a depth of 12–14 cm | | | | |
| Shallow | BDT-2,5 disking to a depth of 10–12 cm | | | | |

out with a SZP-3.6 seeder. Mineral fertilizers (against a background with fertilizers) were applied before pre-sowing cultivation with a rate of $N_{40}P_{40}K_{40}$ kg ai. per 1 hectare of crop rotation area. For the destruction of weeds, herbicides were used in all studied variants.

The area of the plots (5.5–6.0 × 63 m) is 346–378 m$^2$, the accounting area is 100 m$^2$. During the years of research on the conditions of moisture supply of the growing season, 74% of the years were close to average, 26% were insufficiently provided with precipitation. The technique of bookmarking and conducting the experiment and statistical processing of the data obtained were carried out according to the method of B.A. Dospekhov[1] using O.D. Sorokin[2]. The determination of the agrophysical properties of the soil was carried out according to the method of N.A. Kachinsky[3]. Soil moisture was determined by the thermostat-weight method in each 10-cm layer to a depth of 0–100 cm. Productive moisture reserves were calculated taking into account the bulk density and wilting moisture for each 10-cm layer. The data obtained were combined by layers of 0–30 and 0–100 cm. The chemical analysis of soil samples was carried out according to generally accepted methods[4].

## RESULTS AND DISCUSSION

Under the conditions of unstable moisture in the Northern Trans-Urals, the yield, as well as the possibility of effective use of intensification agents (intensive varieties, fertilizers, protective agents, biostimulants), are largely determined by the presence of moisture in the soil. The need for its maximum accumulation and preservation is due to an unfavorable balance between the intake and consumption of moisture, especially in the initial growing season [7, 8].

One of the main practical measures to influence the most rational use of available moisture resources is tillage [9]. In our studies, during the sowing - seedling period of grain, the moisture reserves of the 0–100 cm soil layer were assessed as satisfactory - 90–125 mm (60–83% of the Field Moisture Capacity), in the 0–30 cm soil layer - 32.0–35.7 mm (52–58% of the Field Moisture capacity).

The most consistently high moisture reserves during this period in grain crops seeds (barley), completing the crop rotation for leguminous crops and for repeated wheat, were provided by plowing (96.8–125.0 mm) and moldboard-free loosening by a plow with stands of the SibIME design (93.0 –122.4 mm) to a depth

[1]Dospekhov B.A. Field experiment technique: 4th ed., rev. and add. Moscow: Kolos, 1979.416 p.
[2]Sorokin O.D. Applied statistics on the computer. Krasnoobsk: EPU SB RAAS, 2004.162 p.
[3]Kachinsky N.A. Soil physics. M.: Higher school, 1965. 318 p.
[4]Arinushkina E.V. Manual for Chemical Analysis of Soils. Moscow: Moscow State University Publishing House, 1970.478 p.

of 20–22 cm. When using leguminous crops as a predecessor, resource-saving processing systems (dump-free, combined with the use of SibIME tines) provided moisture reserves in a meter layer during the sowing period - barley shoots similar to the plowing option. The decrease in moisture reserves for small treatments (flat-cut cultivator Smaragd to a depth of 12-14 cm and disking BDT-2.5 to a depth of 10-12 cm) in comparison with the option of plowing was 4.2-7.1 mm, or 4, 3-7.7% in relation to the control (see Fig. 1).

When placing the final crop rotation of a grain crop (barley) on a repeated grain crop (wheat), an increase in the negative impact of resource-saving systems and methods of processing on moisture reserves was noted in comparison with plowing. So, according to the annual plow-free tillage to a depth of 20-22 cm, the decrease in moisture reserves in the meter layer of soil in relation to the option of plowing reached 10.3 mm, or 8.2% in relation to it, for flat-cut processing - 8.6%, according to disking - 28%. In the 0–30 cm soil layer, all studied cultivation systems for both predecessors provided equal moisture conditions. The best conditions for moisture supply for deep moldboard and non-moldboard treatments are explained by the fact that in systems with predominantly shallow treatments, there was a more significant compaction of the soil layer 0–20 cm (by 0.03–0.04 g / cm$^3$) in the layer 10–30 cm - by 0.03–0.07 g / cm$^3$ [10], which worsened the conditions for assimilation of moisture from precipitation in these treatments. In addition, in most years of the research, the precipitation provision was close to the average long-term, the soil during the treatment period had good moisture. Moisture reserves before treatment were 80 mm or more. According to researchers, in these conditions, deep treatments have advantages in moisture accumulation in comparison with shallow treatments[5] [11]. The increase in the negative impact of shallow treatments on moisture accumulation in barley crops for re-wheat compared to crops for grain predecessor (re-wheat) is explained by the shorter post-harvest period.

The composition of the soils of the experimental plot does not have quite favorable properties. Their equilibrium density (1.36–1.41 g / cm$^3$) is far from optimal (1.00–

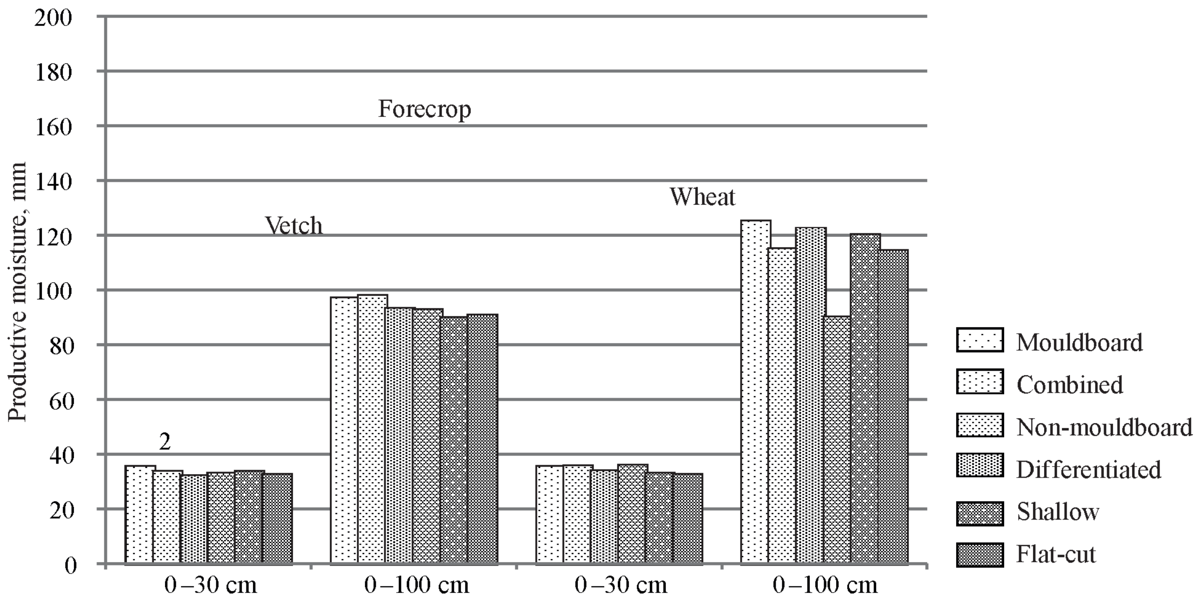


***Рис. 1***. Влияние основной обработки почвы на влагообеспеченность зерновых в период посев – всходы

***Fig. 1***. Effect of basic tillage on moisture availability of grain crops during sowing – sprouting period

[5]Moschenko Y.B. Improvement of the elements of the farming system when growing spring wheat on the chernozems of the steppe zone of Western Siberia: author. dis. Dr. Of Sciences in agriculture. Omsk, 1990.32 p.

1.25 g / cm$^3$) [12]. In this regard, it is important to assess the effectiveness of soil cultivation systems and cultivation methods in the studied systems on the formation of the soil composition regime.

Our data indicate that the density of the topsoil, regardless of the cultivation method and the predecessor, was close to the upper limit of optimal values (1.00–1.25 g / cm$^3$) for a grain crop (see Fig. 2) [13, 14].

An increase in soil density by 0.03 g / cm$^3$ was noted in the treatment of BDT-2.5 by disking by 10-12 cm with a differentiated system for the legume predecessor, for a repeated grain crop - by 0.04 g / cm$^3$ in comparison with the variant of the moldboard processing system.

The importance of the influence of the main processing systems on the peculiarities of the formation of the nutritional regime and the need to study it in relation to zonal and soil conditions have been noted by many scientists [15, 16]. Our research on the nutritional regime has also established a significant effect of tillage and its predecessor on the provision of the arable and sub-arable soil layers with available nutrients (see Table 2). It was revealed that the cultivation of cereals in a grain-fallow crop rotation with the presence of leguminous crops against the background of the application of fertilizers $N_{40}P_{40}K_{40}$ provides favorable conditions for the nutritional regime in the field that closes the crop rotation. On the contrary, in the fourth field of a grain crop after fallow in a crop rotation without a leguminous crop, the content of nitrate nitrogen in the arable layer decreased in comparison with the field with a legume predecessor by 15.5–43.8%, $P_2O_5$ by 39.1–52.1, $K_2$ About 15.1-26.4%. This is due to legumes and spring crops differing in nutrient removal, partial compensation of nitrogen removal by legumes due to symbiotic nitrogen fixation, and a longer period of nitrification in the post-harvest period.

According to both predecessors, the best nutritional conditions, both in the arable layer of 0–0.2 m and in the layer of 0.2–0.4 m, were formed with the moldboard cultivation system, which was facilitated by the better conditions for the agrophysical properties of the soil. Long-term application of treatment without formation turnover, treatment systems with predominantly small treatments led to a decrease in the content of $N – NO_3$ in the arable layer by 12–42%, $P_2O_5$ by 7.1–19.9, $K_2O$ by 6.5–17.1%, which increased in sowing of repeated grain crops.

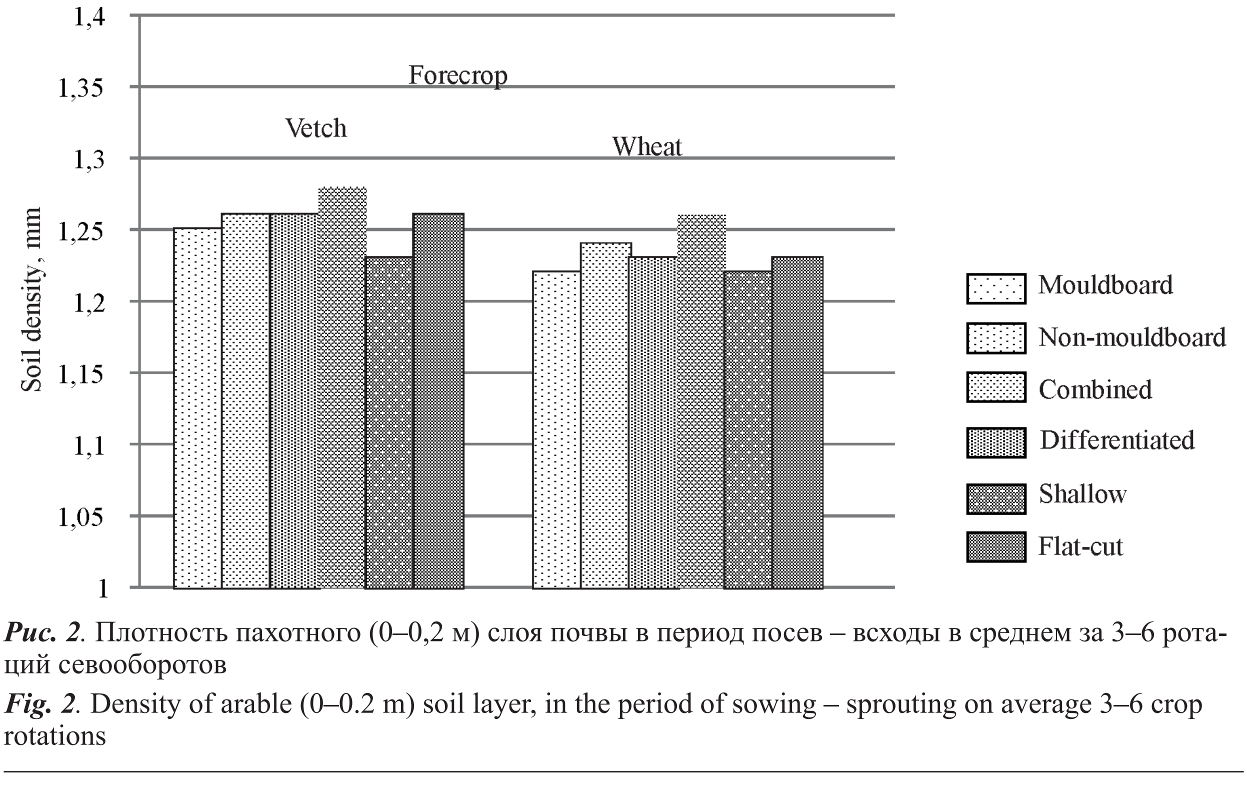


***Рис. 2***. Плотность пахотного (0–0,2 м) слоя почвы в период посев – всходы в среднем за 3–6 ротаций севооборотов

***Fig. 2***. Density of arable (0–0.2 m) soil layer, in the period of sowing – sprouting on average 3–6 crop rotations

**Табл. 2.** Содержание питательных элементов в почве перед посевом зерновых (в среднем за 3–6 ротаций севооборотов)

**Table 2.** Nutrient content before sowing of grain crops (on average for 3–6 crop rotations)

| Soil tillage system | Forecrop | $N–NO_3$, mg / kg soil | | $P_2O_5$ mg / 100 g soil | | $K_2O$, mg / 100 g soil | |
|---|---|---|---|---|---|---|---|
| | | Soil horizon 0–0,2 m | | | | | |
| | | 0–20 | 20–40 | 0–20 | 20–40 | 0–20 | 20–40 |
| Mouldboard | Vetch | 8,84 | 6,26 | 28,10 | 17,26 | 22,85 | 16,00 |
| | Wheat | 6,51 | 5,21 | 15,60 | 9,00 | 17,20 | 11,80 |
| Non-mouldboard | Vetch | 7,78 | 4,35 | 25,26 | 8,81 | 22,55 | 14,70 |
| | Wheat | 5,13 | 4,46 | 13,20 | 5,60 | 16,60 | 11,10 |
| Combined | Vetch | 6,24 | 4,15 | 25,30 | 11,09 | 21,25 | 14,90 |
| | Wheat | 5,27 | 4,29 | 15,40 | 6,40 | 17,75 | 10,80 |
| Differentiated | Vetch | 6,24 | 4,60 | 26,08 | 10,08 | 20,55 | 13,60 |
| | Wheat | 3,78 | 3,55 | 12,50 | 5,20 | 16,80 | 11,30 |
| Shallow | Vetch | 6,88 | 5,07 | 25,70 | 9,96 | 20,35 | 13,70 |
| | Wheat | 5,25 | 3,87 | 15,40 | 6,60 | 15,67 | 9,81 |
| Flat-cut | Vetch | 7,58 | 4,87 | 25,70 | 8,50 | 18,95 | 13,20 |
| | Wheat | 4,26 | 3,30 | 13,70 | 6,60 | 16,08 | 11,58 |
| $LSD_{05}$ Partial effects | On vetch | 0,96 | 0,93 | 1,95 | 1,56 | 1,40 | 1,15 |
| | On wheat | 0,84 | 0,81 | 1,12 | 0,87 | 1,00 | 0,73 |

The general differentiation of the fertility of the arable and sub-arable soil layers for all studied cultivation systems showed the following. There was a decrease in the content of nutrients in the soil layer 0.2–0.4 m in relation to the 0–0.2 m layer: $N – NO_3$ by 13.1–44.1%, $P_2$ $O_5$ by 38.6–66.9 and $K_2$ O by 28.0–39.2%. The highest negative differentiation was noted in the content of P2 O5, and it was the smallest for the dump processing system - 38.6–42.3%, while for resource-saving systems - 51.8–66.9%.

Analysis of the influence of the studied soil cultivation systems on crop yields showed that in a grain-fallow crop rotation, when placed on a legume crop, resource-saving cultivation systems provided almost equal barley yields to the moldboard cultivation system. Against the background of natural fertility, it amounted to 2.57–3.03 t / ha, with the use of fertilizers - 3.47–3.65 t / ha (see Fig. 3).

After the legume predecessor in the moldboard and resource-saving processing systems, favorable conditions for agrophysical properties, nutritional regime and, in particular, nitrogen nutrition for leguminous crops developed: nitrogen in the soil was replenished both due to the current nitrification due to a longer post-harvest period, and due to the symbiotic fixation of air nitrogen. In this regard, they obtained indicators of economic and energy efficiency, which are close to the variant of the moldboard processing system. The differences in net income between the moldboard and resource-saving processing systems did not exceed 0.6–3.7% against the background without the use of fertilizers, and 2.6–6.0% with fertilizers.

The highest efficiency was noted for the moldboard processing system: net income amounted to 14.67 thousand rubles / ha against the background without fertilizers and 22.75 thousand rubles / ha against the background of their application; the energy coefficient is 2.65 and 2.75, respectively [17].

In the crop rotation without the presence of leguminous crops, where barley was cultivated on repeated wheat, there was a significant decrease in its yield according to resource-saving processing systems: against the background of natural fertility by 0.09-0.27 t / ha (by 3.8-11.4%) , with the use of fertilizers by 0.07–0.40 t / ha (by 2.0–11.1%). This led to a decrease in net income in the cultivation of barley in comparison with the legume predecessor by 31–44.1% [17]. This decrease is due to a decrease in the content of nitrate nitrogen, mobile phosphorus and potassium in the soil by

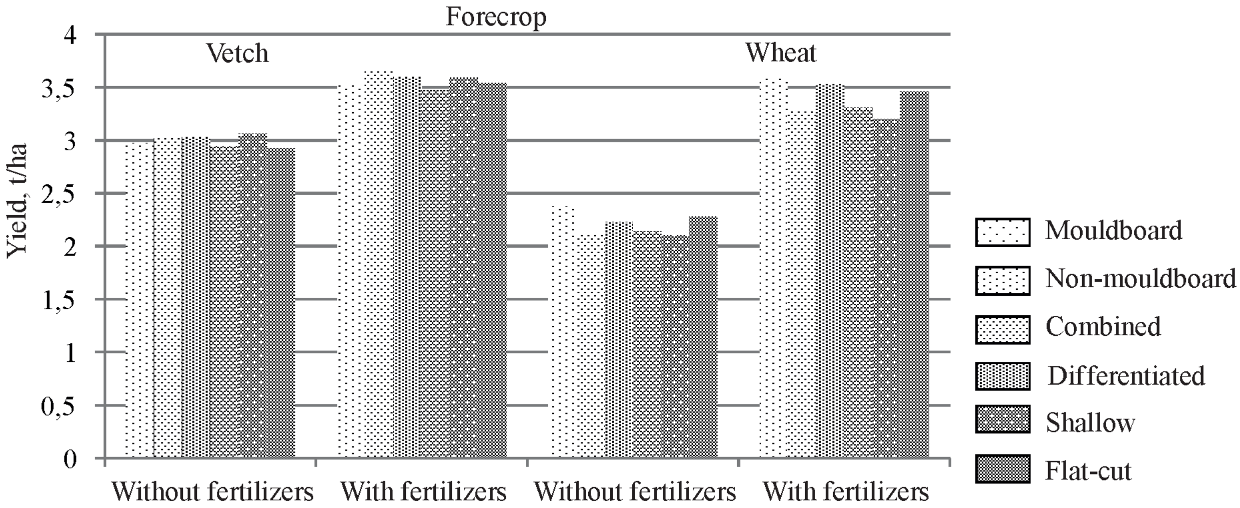


***Рис. 3.*** Урожайность ячменя в среднем за 3–6 ротаций севооборотов
***Fig. 3.*** Barley yield on average for 3–6 crop rotations

non-moldboard and shallow tillage, especially in crop rotation without the presence of leguminous crops. In this case, in the cultivation of barley on recycled wheat, a stable advantage of the dump system was noted, which is explained by more favorable conditions for providing moisture, soil composition and nutrient content.

## CONCLUSIONS

1. On the dark gray forest soils of the northern forest-steppe of the Northern Trans-Urals in grain-fallow crop rotation during the cultivation of a grain crop - the fourth crop after steam for the legume predecessor (spring vetch) - it is recommended to use the main processing systems with minimization elements - moldboard-free and combined with moldboard-free loosening by a plow with stands SibIME by 20–22 cm, differentiated with flat-cut processing by 12–14 cm and disking by 10–12 cm. These processing systems after leguminous plants for barley provided conditions of the water regime, soil composition, nutritional regime close to the moldboard system, the formation of an almost equal moldboard system yield processing: against the background of natural fertility - 2.97-3.03 t / ha, with the use of $N_{40}P_{40}P_{40}$ - 3.47-3.65 t / ha, as well as economic efficiency.

2. The use of resource-saving processing systems in grain-fallow crop rotation without leguminous crops for grain crops for repeated wheat led to a decrease in the reserves of productive moisture in a meter layer of soil by 8.6-28.0%, a significant deterioration in the nutritional regime, especially nitrogen (by 15, 5–43.8%) and phosphorus (by 39.1–51.1%), with a negative differentiation of the fertility of the soil profile, a decrease in the yield of barley grain by 0.09–0.40 t / ha, a decrease in net income by 31– 44%.

3. To increase the potential of soil fertility and productivity of cereal crops, completing the link of crop rotation along the moldboard and resource-saving systems of basic processing, it is advisable to place and sow them on the legume predecessor.

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