https://doi.org/10.26898/0370-8799-2023-11-1 Тип статьи: оригинальная
УДК: 631.81:631.89:633.854.78 Type of article: original

ВЛИЯНИЕ ПОСЛЕДЕЙСТВИЯ МИНЕРАЛЬНЫХ УДОБРЕНИЙ ПРИ ВОЗДЕЛЫВАНИИ ЯЧМЕНЯ ПОСЛЕ ПОДСОЛНЕЧНИКА

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Представлены результаты исследований за 2021, 2022 гг. по влиянию последействия различных доз минеральных удобрений, вносимых под подсолнечник, на продуктивность и качество ярового ячменя сорта Камашевский. Полевые опыты заложены в условиях Ульяновской области на черноземе выщелоченном тяжелосуглинистом. Изучали четыре фона минеральных удобрений: N_0, N_{30}, $N_{30}P_{30}K_{30}$, $N_{60}P_{30}K_{30}$ кг д.в./га. Метеоусловия были контрастными в годы исследований, что позволило более полно оценить эффективность последействия удобрений. Технология возделывания ячменя включала весеннюю разделку растительных остатков подсолнечника дискатором и модульной бороной, посев зерновой сеялкой и прикатывание. Ячмень проявил наибольшую отзывчивость на последействие минеральных удобрений в дозе $N_{60}P_{30}K_{30}$ кг д.в./га. Урожайность зерна на данном варианте составила 2,11 т/га, что на 1,05 т/га выше по сравнению с неудобренным вариантом. На данном агрофоне получено более крупное зерно (масса 100 зерен составила 48,4 г, на контроле – 44,4 г) с высоким содержанием белка 12,7% (на контроле – 11,5%). Проведение корреляционно-регрессионного анализа позволило выявить прямую положительную взаимосвязь между накоплением сухого вещества и продуктивностью ячменя (R^2 = 0,96). Установлено, что с увеличением дозы азотных удобрений на каждые 10 кг д.в./га наблюдается повышение содержания сырого белка в зерне на 0,2%. Содержание белка в зерне зависело от условий влагообеспеченности года. Возделывание ячменя после подсолнечника агрономически целесообразно на фоне последействия минеральных удобрений. При отсутствии удобрений продуктивность ячменя после подсолнечника резко снижается. Кроме того, необходимы тщательный контроль за засоренностью посевов ячменя (в том числе в связи с появлением большого количества падалицы подсолнечника) и своевременное проведение химической прополки.

Ключевые слова: ячмень яровой, минеральные удобрения, последействие, продуктивность, сырой белок

INFLUENCE OF MINERAL FERTILIZERS AFTER-EFFECT WHEN CULTIVATING BARLEY AFTER SUNFLOWER

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The results of research for 2021, 2022 on the impact of the after-effect of different doses of mineral fertilizers applied to sunflower on productivity and quality of spring barley of the Kamashevsky variety are presented. Field experiments were laid in the conditions of the Ulyanovsk region on chernozem leached heavy loamy soil. Four backgrounds of mineral fertilizers were studied: N_0, N_{30}, $N_{30}P_{30}K_{30}$,

$N_{60}P_{30}K_{30}$ kg a.i./ha Meteorological conditions were contrasting in the years of research, which allowed a more complete assessment of the effectiveness of fertilizer after-effect. Barley cultivation technology included spring cutting of sunflower crop residues with a discator and a modular harrow, sowing with a grain drill and rolling. Barley showed the greatest responsiveness to the after-effect of mineral fertilizers at a dose of $N_{60}P_{30}K_{30}$ kg a.i./ha. Grain yield in this variant was 2.11 t/ha, which is 1.05 t/ha higher compared to the unfertilized variant. On this agricultural background, a larger grain was obtained (the weight of 100 grains was 48.4 g, on the control - 44.4 g) with a high protein content of 12.7% (on the control – 11.5%). Correlation and regression analysis revealed a direct positive relationship between dry matter accumulation and barley productivity (R^2 = 0,96). It was found that with an increase in the dose of nitrogen fertilizers for every 10 kg a.i./ha, an increase in the crude protein content of grain by 0.2% was observed. Protein content in grain depended on the moisture conditions of the year. Cultivation of barley after sunflower is agronomically expedient on the background of mineral fertilizers aftereffect. In the absence of fertilizers, the productivity of barley after sunflower sharply decreases. In addition, it is necessary to carefully control the weediness of barley crops (including the emergence of large amounts of sunflower fallen seed) and timely chemical weeding.

Keywords: spring barley, mineral fertilizers, after-effect, productivity, crude protein

Для цитирования: *Никифорова С.А.* Влияние последействия минеральных удобрений при возделывании ячменя после подсолнечника // Сибирский вестник сельскохозяйственной науки. 2023. Т. 53. № 11. С. 5–13. https://doi.org/10.26898/0370-8799-2023-11-1

For citation: Nikiforova S.A. Influence of mineral fertilizers after-effect when cultivating barley after sunflower. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2023, vol. 53, no. 11, pp. 5–13. https://doi.org/10.26898/0370-8799-2023-11-1

Конфликт интересов

Автор заявляет об отсутствии конфликта интересов.

Conflict of interest

The author declares no conflict of interest.

INTRODUCTION

Spring barley is the most important fodder crop occupying annually about 10% of the sown area in the Ulyanovsk region (95-104 thousand hectares) with a yield of 15-20 c/ha. It is important to cultivate it according to adaptive technology, taking into account the responsiveness of the crop to various agronomic practices – forecrops, doses and types of applied mineral fertilizers, crop protection system, etc. [1–4].

The role of a forecrop in crop cultivation technology is difficult to overestimate [5-9]. Studies [6] on leached chernozem showed that spring wheat and oats are the worst forecrops for barley due to the increase in weediness of crops, plant infestation by diseases and, as a consequence, a decrease in crop yields. Placement of barley on spring wheat and oats reduced the crude protein content by 0.8-0.9%.

Widespread sunflower crops and late dates of its harvesting do not always allow to till the soil in the autumn, which requires the study of the effectiveness of sunflower as a forecrop for grain crops from an agronomic point of view. Often agricultural producers practice cultivation of barley after sunflower. As experience shows, barley gives the same yield in direct sowing after sunflower with a stubble seeder as in traditional cultivation technology[1].

It is known that barley shows increased requirements to the level of mineral nutrition, because of this it is responsive to the direct action of mineral fertilizers and, first of all, starting doses [10-13]. Feeding during the growing season is ineffective due to the short growing season of the crop.

Applying mineral fertilizers to the preceding crop allows providing barley with accessible elements of mineral nutrition in the early

[1]Pat. No. 2714706 C1 Russian Federation, MPK A01C 7/00, No. 2019124821. Method of spring barley cultivation by direct sowing / A.L. Toigildin, D.E. Ayupov, A.S. Galkin; applicant – Ulyanovsk State Agrarian University named after P.A. Stolypin; applied 02.08.2019; published 19.02.2020.

development period [14–16]. However, in this case, it is important to assess the productivity of the crop depending on the background of mineral fertilizers of the preceding crop. With the high cost of mineral fertilizers, this issue becomes particularly relevant.

The purpose of the research is to present a comprehensive assessment of the after-effect of mineral fertilizers when cultivating barley after sunflower.

MATERIAL AND METHODS

In 2020 and 2021, studies were conducted to develop elements of sunflower cultivation technology using various doses of mineral fertilizers, then assessing the after-effect of the studied factors on the productivity of spring barley. Sunflower harvesting was carried out late (October – December). The field was not tilled in autumn. Soil preparation for sowing was done in the spring period: the first treatment with a disk harrow BDM 3 × 4, the second with a modular harrow BM-4.5. The beginning of crop germination was noted on May 18–25. Care for the crops during vegetation included protection from weeds in the tillering phase with the Balet, EC (in a dose of 0.4 l/ha) preparation.

The field experiment studied four backgrounds of mineral fertilizers in after-effect: N_0, N_{30}, $N_{30}P_{30}K_{30}$, $N_{60}P_{30}K_{30}$. The experiment was repeated three times, with systematic placement of the plots. The accounting area of the plot was 15 × 22.4 = 336 m². Barley sowing in 2021 was carried out on May 17, in 2022 – on May 9 with a grain seeder SZ-3.6 across the sowing of the previous crop without fertilizers, at a depth of 5–6 cm with a seeding rate of 4.5 million germinating seeds/ha. The harvest was carried out with a selective combine Sampo-500 at the stage of full ripeness, with further translation of the data to 100% purity and 14% moisture. As mineral fertilizers, azophoska with a content of $N_{15}P_{15}K_{15}$ and ammonium nitrate with a nitrogen content of 34.4 kg a.i./ha were used. Fertilizers were applied before sowing sunflower in the previous year.

The object of the study was a promising, zoned in the Middle Volga region medium-ripe variety of spring barley (*Hordeum vulgare* L.) grain-forage direction Kamashevsky. The variety is a steppe morpho-biotype, moderately resistant to fungal diseases, resistant to loose smut. It is prone to lodging with the application of high rates of nitrogen fertilizers and an excessive seeding rate. The protein content in the grain reaches 14%. The variety is valuable for quality[2].

Before sowing, the reserves of productive moisture were unsatisfactory (in the layer 0–10 cm – 4.7–6.5 mm, 0–30 cm – 17.9–21.5 mm). The low moisture reserve was also due to the fact that spring mechanical soil treatments were carried out for the disintegration of sunflower plant residues, which led to additional loss of moisture reserves.

From May to July, the sum of active temperatures amounted to 1947°, with the norm being 1600°. The intensely high temperature regime in June contributed to the accelerated pace of barley development. During the plant development period from the third ten-day period of May to the first ten-day period of August, 105.5 mm of precipitation fell, with the norm being 166 mm.

The vegetation period of 2022, on the contrary, was characterized by cool and rainy weather in May, moderate temperature regime and precipitation in June, intensive torrential rains in July, and hot, dry weather in August. The amount of precipitation in May was 65.7 mm with a norm of 39.0 mm (168% of the norm). The rains were significant, so early in the second ten-day period of May, a dangerous phenomenon was noted – soil overmoisture. In June, the weather was unstable: periods of warm, and on some days hot weather alternated with short periods of cooling. In July, the weather was predominantly very warm with rains of varying intensity.

[2]New super variety of barley Kamashevsky – what is its strength, the scientists are explaining. URL: https://www.agroxxi.ru/zhurnal-agromir-xxi/stati-rastenievodstvo/novyi-super-sort-jachmenja-kamashevskii-v-chem-ego-sila-rasskazyvayut-uchenye.html (accessed on 05.07.2023).

The maximum air temperature on the warmest days rose to 30–32 °C. The showers were local, accumulating 140 mm over the month (the long-term average norm is 69 mm). The sum of active temperatures from May to July was 1544°, with the norm being 1600°. During the development period of the plants from May to July inclusive, 250 mm of precipitation fell. In 2021, the HTC was 0.5, in 2022 – 1.6, with the norm being 1.0.

All registrations, observations, and analyses were conducted according to generally accepted methods and corresponding GOST standards. Mathematical processing of experimental data was carried out using methods of dispersion and correlation analysis.

RESULTS AND DISCUSSION

In all years of research, sunflower harvesting took place late (October – December) due to the prolonged ripening of the crop caused by prolonged precipitation in the autumn period. Consequently, the chopping of sunflower stubble was carried out in the spring period. It should be noted that shallow soil tillage (8–10 cm) caused the growth of sunflower volunteers, as well as weeds. Conducting chemical weeding with a tank mixture against perennial and annual weeds became a mandatory and effective agricultural practice.

The research results revealed a high responsiveness of the spring barley variety Kamashevsky to the after-effect of mineral fertilizers applied under sunflower in the preceding year, the effectiveness of which primarily depended on the moisture conditions of the year.

Depending on the background of mineral fertilizers, barley sowing significantly differed in the rates of biomass accumulation and in the content of nutrients in the plants (see Fig. 1, Table 1). The highest accumulation of dry matter was noted in the $N_{60}P_{30}K_{30}$ variant (56 c/ha), which was 1.9 times higher than the control (30 c/ha).

Due to insufficient moisture, the plants were in a suppressed state, with accelerated passage of interphase periods observed. For instance, the total nitrogen content in barley plants during the shooting stage varied from 2.32 to 2.66% and was assessed as low. By the end of vegetation, in terms of total nitrogen content in the vegetative mass of barley, the advantage was with the experimental variants – 1.27–1.37% (on the control – 1.16%). No clear dependence on the after-effect of mineral fertilizers was found for the total phosphorus and potassium content in the green mass of plants.

The after-effect of mineral fertilizers manifested in the improvement of nitrogen

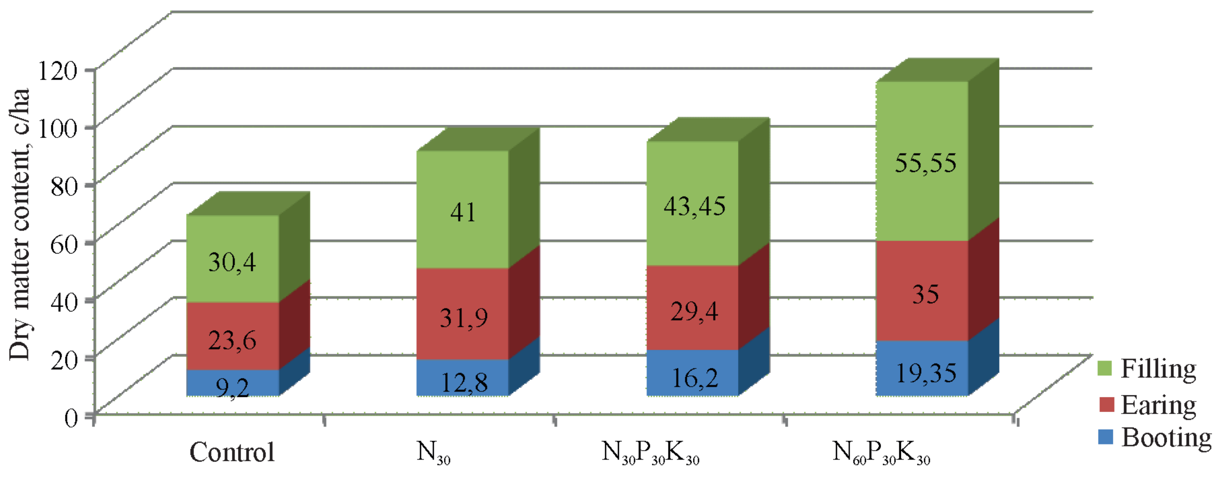

Рис. 1. Влияние последействия минеральных удобрений на накопление сухого вещества посевами ячменя

***Fig.* 1.** Effect of mineral fertilizers on dry matter accumulation in barley crops

Табл. 1. Динамика элементов минерального питания в растениях ячменя по фазам развития
Table 1. Dynamics of mineral nutrition elements in barley plants by phases of development

Experiment option	Barley development phase								
	booting			earing			filling		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
N_0	2,32	1,48	5,59	1,47	1,06	2,58	1,16	1,11	1,68
N_{30}	2,66	1,24	5,42	1,37	0,95	2,66	1,37	0,89	1,50
$N_{30}P_{30}K_{30}$	2,42	1,37	4,56	1,57	1,02	2,42	1,33	0,98	1,63
$N_{60}P_{30}K_{30}$	2,43	1,2	4,59	1,30	0,93	2,63	1,27	0,96	1,47

nutrition in barley and, consequently, contributed to the formation of a larger above-ground mass compared to the unfertilized variant already at the initial stages of barley development (see Fig. 2).

Barley sowings on the variants with the application of mineral fertilizers had more intense coloration and stem density.

At the beginning of barley vegetation, a higher nitrate content was noted in the soil compared to the control (+2–5 mg/kg of soil to the control). The trend of increased nitrogen provision remained before the barley harvest.

Correlation-regression analysis showed a strong relationship between the accumulation of dry matter in plants (y) and the dose of nitrogen fertilizers (x) in after-effect. The linear dependence is described by equations of the type:

shooting $y = 0{,}17x + 9{,}31$ ($R^2 = 0{,}90$); (1)

earing $y = 0{,}19x + 24{,}27$ ($R^2 = 0{,}93$); (2)

filling $y = 0{,}42x + 30{,}0$ ($R^2 = 0{,}99$). (3)

Equation (3) shows that for every 10 kg a.i./ha of applied nitrogen in after-effect, there was an average increase in the dry matter accumulation in plants of 4.2 c/ha.

The productivity of barley significantly depended on the after-effect of mineral fertilizers applied under sunflower in the previous year, proportionally to the level of mineral nutrition (see Table 2).

Despite the fact that barley sowing in 2022 was carried out 8 days earlier than in 2021, the crop reached full ripeness 9 days later (August 5) due to increased precipitation.

In 2021, due to the late sowing date and dry conditions in June, low productivity of barley was formed. Nevertheless, a significant after-effect of mineral fertilizers was observed. The grain yield increase compared to the control was 0.24–0.33 t/ha (20.7–28.5%), with no significant differences between the fertilized variants. In 2022, a reliable increase in barley

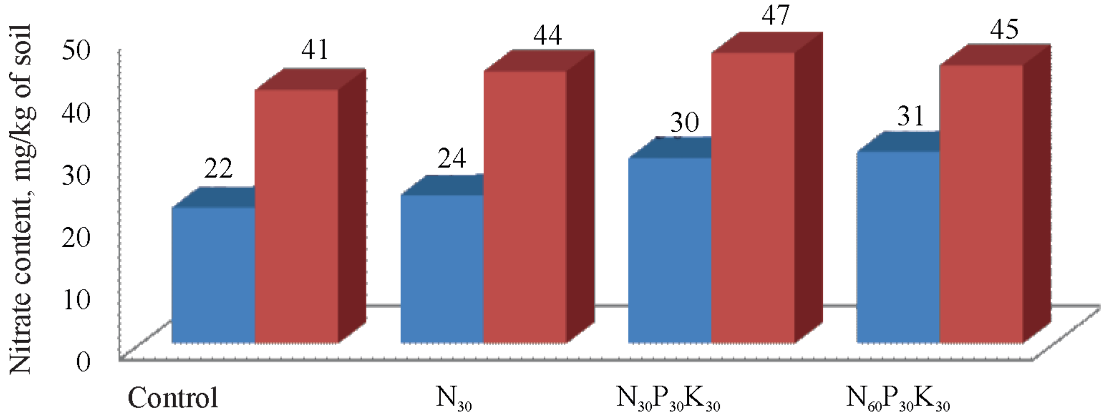

Рис. 2. Содержание нитратов в почве в зависимости от последействия минеральных удобрений, мг/кг почвы

Fig. 2. Nitrate content in soil depending on the after-effect of mineral fertilizers, mg/kg of soil

Табл. 2. Влияние последействия минеральных удобрений на продуктивность и качество ячменя (2021, 2022 гг.)

Table 2. Impact of the mineral fertilizers after-effect on productivity and quality of barley (2021, 2022)

Experiment option	Grain yield, t/ha				Weight of 1000 grains, g	Crude protein, %	Gross protein yield, kg/ha
	2021	2022	Average	± t/ha			
Control	1,16	0,95	1,06	–	44,4	11,5	122
N_{30}	1,4	1,31	1,36	+0,3	46,0	11,8	161
$N_{30}P_{30}K_{30}$	1,43	1,45	1,44	+0,38	45,9	11,9	172
$N_{60}P_{30}K_{30}$	1,49	2,72	2,11	+1,05	48,4	12,7	268
LSD_{05} 2021 p = 3,05%, 2022 p = 3,95%	0,14	0,19					

yield was also observed at all levels of mineral nutrition. The greatest responsiveness of barley was shown to the after-effect of $N_{60}P_{30}K_{30}$ kg a.i./ha (+1.77 t/ha).

On average, over the years of research, cultivating barley after sunflower, depending on the doses of mineral fertilizers in after-effect, allowed to obtain an additional 0.30–1.05 t of grain/ha compared to the unfertilized variant.

A direct positive correlation was established between the accumulation of dry biomass in plants and the productivity of barley, which is described by a linear equation of the type

$$y = 0{,}42x – 2{,}97\ (R^2 = 0{,}96),$$

where y – barley yield; t/ha, x – dry biomass of plants, c/ha.

The application of mineral fertilizers contributed to the improvement of quantitative and qualitative indicators of the grain. For instance, the weight of 1000 grains on the control was 44.4 g, on the fertilized variants – 46.0–48.4 g. The largest grain was obtained in the variant with the after-effect of an increased dose of mineral fertilizers ($N_{60}P_{30}K_{30}$).

On average for 2021 and 2022, in terms of raw protein content in the grain, the advantage was also with the experimental variants. A direct positive correlation was found between the content of raw protein in barley grain and the dose of mineral nitrogen. The equation is as follows

$$y = 0{,}02x + 11{,}36\ (R^2 = 0{,}91),$$

where y – raw protein content in grain, %; x – dose of nitrogen fertilizers, kg a.i./ ha (the equation is valid for raw protein content of 11.5–12.7% and nitrogen doses of 0–60 kg a.i./ ha). The equation shows that with an increase in the dose of nitrogen fertilizers by every 10 kg a.i./ ha, there is a 0.2% increase in the protein content.

Under the influence of the after-effect of mineral fertilizers, significant changes were observed in the structure of the barley yield (see Table 3).

The after-effect of fertilizers manifested in the formation of a greater number of productive stems in the experimental variants (25–98 pcs./m² higher than the control). An increase in the length of the ear by 0.4–2.4 cm, the grain weight per ear by 0.08–0.18 g, and the ear grain content by 1.4–3.3 pcs./plant were noted. An increase in plant height was directly proportional to the doses of mineral fertilizers applied under sunflower (44 cm in control, 48–59 cm in the experimental variants).

Correlation analysis of productivity elements revealed a direct positive relationship between barley yield and the number of productive stems (r = 0.99), length of the ear (r = 0.98), and the ear grain content (r = 0.97), as well as the weight of grain from one ear (r = 0.96) (see Table 4). The grain weight directly depended on its quantity from one ear (r = 1.0).

CONCLUSIONS

1. The studies revealed a high responsiveness of the spring barley variety Kamashchevsky when cultivated on leached chernozem to the after-effect of mineral fertilizers applied under sunflower.

Табл. 3. Структура урожая ячменя в зависимости от последействия минеральных удобрений
Table 3. Barley yield structure depending on the after-effect of mineral fertilizers

Experiment option	Barley yield structure indicator						
	Number of productive stems, pcs./m^2	Tillering coefficient	Ear length, cm	Grain weight per ear, g	Number of grains, pcs./plant	Straw weight, g/plant	Plant height, cm
Control	330	1,26	4,7	0,46	9,9	0,43	44
N_{30}	355	1,30	5,1	0,54	11,3	0,52	50
$N_{30}P_{30}K_{30}$	375	1,43	5,0	0,57	11,8	0,56	48
$N_{60}P_{30}K_{30}$	428	1,47	6,3	0,64	13,2	0,59	59

Табл. 4. Матрица коэффициентов корреляции между продуктивностью и элементами структуры урожая
Table 4. Matrix of correlation coefficients between productivity and elements of the yield structure

Indicatoe	Yield, t/ha	Number of productive stems, pcs./m^2	Ear length, cm	Grain weight per plant, g	Number of grains per plant, pcs.	Straw weight from one plant, g	Plant height, cm
	1	2	3	4	5	6	7
1	1,0						
2	0,99*	1,0					
3	0,98*	0,95*	1,0				
4	0,96*	0,97*	0,89	1,0			
5	0,97*	0,98*	0,91	1,0**	1,0		
6	0,87	0,9	0,77	0,97*	0,96*	1,0	
7	0,98*	0,95	0,99*	0,92	0,94	0,82	1,0

* Significant at the level of $p = 0{,}05$.
** Significant at the level of $p = 0{,}01$.

2. Barley sowing on the background of fertilizers formed 11–26 c of dry matter/ha more than the control. Experimental plants throughout the vegetation period had a higher content of total nitrogen in the green mass.
3. The highest productivity of barley was found in the after-effect of $N_{60}P_{30}K_{30}$ kg a.i./ha, which provided an increase of 1.05 t/ha compared to the unfertilized variant. In the experimental variants, larger grains were obtained (weight of 1000 grains 46–48.4 g, in the control – 44.4 g) with a high protein content of up to 11.8–12.7% (in the control 11.5%).
4. The correlation-regression analysis revealed a direct positive relationship between the accumulation of dry matter and the productivity of barley ($R^2 = 0.96$). It was established that with an increase in the dose of nitrogen fertilizers by every 10 kg a.i./ha, there is an increase in the raw protein content in the grain by 0.2%.
5. Cultivating barley after sunflower is effective against the background of the after-effect of mineral fertilizers in the dose of $N_{30–60}P_{30}K_{30}$ kg a.i./ha, which is reflected in the increase in productivity and quality of the grain.

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Дата поступления статьи / Received by the editors 12.09.2023
Дата принятия к публикации / Accepted for publication 24.10.2023
Дата публикации / Published 15.12.2023