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PRODUCTIVITY OF SOYBEAN DEPENDING ON THE PREDECESSOR AND FERTILIZATION SYSTEM IN THE CONDITIONS OF THE STEPPE OF UKRAINE

Sokolovska I.M. *– Ph.D., Associate Professor,*
Associate Professor at the Department of Crop Production and Agricultural Engineering,
Kherson State Agrarian and Economic University
Mashchenko Yu.V. *– Ph.D.,*
Head of the Scientific and Technological Department for Soil Fertility Conservation,
Institute of Agriculture of the Steppe, National Academy of Agrarian Sciences
Zharko D.A. *– Postgraduate at the Department of Crop Production*
and Agricultural Engineering,
Kherson State Agrarian and Economic University

The correct choice of a predecessor crop for soybean cultivation in short rotation crop rotations can increase its productivity. It is considered that the best predecessors for soybean are spring and winter cereals. There are recommendations for placing soybeans after corn, potatoes, sugar beets, and vegetable crops. Technological methods of growing soybeans in repeated sowings and in monoculture are not sufficiently studied. The fertilization system plays an important role in increasing the yield of any agricultural crop. Determining the fertilization system for soybeans should take into account not only the physiological characteristics of this crop but also the impact on the fertility of the predecessor soil.

Field research was conducted on the fields of the Institute of Agriculture of the Steppe NAAS from 2019 to 2023. Soybeans of the Zlatoslava variety were grown in a short grain-row crop rotation with 60% soybean saturation, which had the following rotation: 1. Soybean; 2. Winter wheat; 3. Soybean; 4. Corn for grain; 5. Soybean. The meteorological characteristics of the research were marked by variability over the years, which allowed for establishing a reliable influence of factors studied under different moisture and temperature weather conditions.

In our research, fertilization systems had the most significant impact on soybean yield and productivity. Higher grain yield, grain units yield, feed units, and digestible protein units were achieved under the organo-mineral fertilization system after corn for grain as a predecessor: 2.14 t/ha, 4.03 t/ha, 3.47 t/ha, and 0.68 t/ha respectively. Repeated soybean sowings slightly lagged behind in these indicators, but the difference was not significant. Under the mineral fertilization system, the predecessor factor reduced the effectiveness of fertilizer action, and the difference in soybean yield and productivity based on different predecessors was significant. Therefore, the best predecessors for soybean cultivation in a grain-row crop rotation with up to 60% soybean saturation in the conditions of the northern Steppe of Ukraine were corn for grain and soybean. The use of the organo-mineral fertilization system after winter wheat as a predecessor allowed for achieving soybean crop productivity levels comparable to the best predecessors.

Key words: *soybean, predecessors, fertilization systems, soybean yield, productivity.*

Соколовська І.М., Мащенко Ю.В., Жарко Д.А. Продуктивність сої залежно від попередника та системи удобрення в умовах Степу України

Правильний вибір попередньої культури для вирощування сої в короткоротаційній сівозміні дає можливість збільшити її продуктивність. Вважається, що кращі попередники для сої є ярі та озимі зернові культури. Існують рекомендації щодо розміщення сої після кукурудзи, картоплі, цукрових буряків й овочевих культур. Технологічні прийоми вирощування сої в повторних посівах та в монокультурі вивчені недостатньо. Важливу роль у підвищенні врожайності будь якої сільськогосподарської культури відіграє система удобрення. Визначення системи удобрення сої необхідно не лише з урахуванням фізіологічних особливостей даної культури, але й врахування впливу на родючість ґрунту попередника.

Польові дослідження проводили на полях лабораторії землеробства Інституту сільського господарства Степу НААН протягом 2019–2023 рр. Сою сорту Златослава вирощували у короткоротаційній зерно-просапній сівозміні з насиченням соєю на 60 %, яка мала наступне чергування: 1. Соя; 2. Пшениця озима; 3. Соя; 4. Кукурудза на зерно; 5. Соя. Метеорологічна характеристика проведення досліджень відмічена мінливістю за роками, що дало можливість встановити достовірний вплив факторів, які вивчали з різними за зволоженням та температурним режимом погодними умовами.

Найбільш суттєво на урожайність та продуктивність сої в наших дослідах впливали системи удобрення. Вищі показники урожаю зерна, збору зернових, кормових одиниць та перетравного протеїну були за органо-мінеральної системи удобрення по попереднику кукурудза на зерно: 2,14 т/га, 4,03 т/га, 3,47 т/га та 0,68 т/га відповідно. Повторні посіви сої дещо поступалися за вказаними показниками, але різниця була не істотною. За мінеральної системи удобрення фактор попередник зменшував ефективність дії добрив і різниця урожайності та продуктивності сої по різних попередниках була достовірною. Кращими попередниками для вирощування сої в зерно-просапній сівозміні з насиченням соєю до 60 % в умовах північного Степу України були кукурудза на зерно та соя. Використання органо-мінеральної системи по попереднику пшениця озима давало можливість формувати продуктивність посівів сої на рівні кращих попередників.

Ключові слова: *соя, попередники****,*** *системи удобрення, урожайність сої, продуктивність.*

Formulation of the problem. The proper selection of a previous crop for soybean cultivation in short rotation crop rotations allows for increased productivity not only by reducing weed infestation, preventing diseases and pest damage, but also by more rational use of nutrients from the soil and optimization of water regime. It is considered that the best predecessors for soybean are spring and winter cereals, as they free up fields faster, allowing for a longer period to carry out all soil cultivation operations. There are recommendations for placing soybean after corn, potatoes, sugar beets, and vegetable crops. Insufficiently studied are the technological practices of growing soybeans in repeated crops and in monoculture.

An important role in increasing the yield of any agricultural crop is played by the fertilization system. Soybean is quite demanding in terms of mineral nutrition; to produce 1 ton of seeds, it requires up to 70–90 kg of nitrogen, 15–20 kg of phosphorus, 30–40 kg of potassium, 8–10 kg of magnesium, and 18–21 kg of calcium. Definition the fertilization system for soybeans should take into account not only the physiological characteristics of this crop but also the activity of the previous crop.

Analysis of recent research and publications. Among all leguminous crops, soybean is the most valuable crop and in recent decades has attracted special attention from farmers. Soybean ranks high among oilseeds in terms of oil production volumes and contains essential nutrients in its seeds like no other [1, 2, 3, 4, 5, 6, 7, 8].

Soybean is one of the most effective biological nitrogen fixers, second only to perennial legumes. According to various researchers, soybean can meet 65–80 % of its nitrogen needs and leave over 30 % of fixed nitrogen in post-harvest and root residues [3, 4, 9].

Soybean is an excellent predecessor for many agricultural crops in crop rotations. It has been proven that high yields are obtained after soybean when cultivating winter and spring cereals, and a good economic result is achieved with a soybean-winter wheat rotation. Soybean as a predecessor for corn gives a yield that is 0.3–0.4 t/ha higher than after other non-leguminous crops. As a predecessor for winter wheat, soybean is comparable to crops like alfalfa and corn [10, 11, 12, 13, 14, 15].

Studies have shown that including leguminous crops, particularly soybeans, in crop rotations leads to increased yields and improved quality. Introducing short rotation crop systems where soybeans are planted repeatedly positively impacts not only the productivity of subsequent crops after soybeans but also overall crop rotation productivity [16, 17, 18, 19, 20, 21],

Soybean is a strategic crop capable of addressing the protein deficit issue and therefore requires significant attention. Despite increasing production volumes of soybeans in Ukraine and globally, its productivity is not yet sufficient. Increasing cultivation areas alone cannot realize the full potential of this crop.

Developing optimal plant fertilization systems for soybeans and improving cultivation technology are important and relevant tasks. The reaction of soybeans to the comprehensive application of different types of fertilizers, especially with organic components in agroecosystems, remains insufficiently studied. Rapid climate changes, inadequate plant moisture supply, and temperatures significantly exceeding average annual values necessitate the development of scientifically sound fertilization systems for soybeans in the Ukrainian Steppe [22, 23, 24, 25, 26, 27, 28, 29].

Research task. Justifying the level of yield and productivity of soybeans when grown in short rotation crop rotations depending on predecessors and fertilization systems in the conditions of the northern Steppe of Ukraine.

Materials and methods of research. Field research, which studied the influence of predecessors and fertilization systems on soybean productivity, was conducted in the fields of the Institute of Agriculture of the Steppe NAAS during 2019–2023. The random replication method was used. Soybeans of the Zlatoslava variety (originator – Institute of Agriculture of the Steppe NAAS) were grown in a grain-row short rotation crop rotation with a 60 % saturation of soybeans, which had the following rotation: 1. Soybean; 2. Winter wheat; 3. Soybean; 4. Corn for grain; 5. Soybean.

The wide-row sowing method (row spacing 0.45 m), sowing date in the first decade of May, sowing rate 800 thousand/ha. The research was two-factorial: Factor A – three predecessors: 1. Winter wheat; 2. Corn for grain; 3. Soybean. Factor B – fertilization systems: 1. Without fertilizers; 2. Mineral fertilization system ($N_{40}P_{40}K_{40}$); 3. Organic-mineral ($N_{40}P_{40}K_{40}$ + by-products of the previous crop). Mineral fertilizers were applied before primary soil tillage in autumn.

The early-ripening Zlatoslava soybean variety was included in the State Register of plant varieties suitable for distribution in Ukraine in 2018. The variety is resistant to anthracnose, powdery mildew, septoria, bacterial blight, fusarium, viral mosaic, and pest damage. It is characterized by high resistance to drought, lodging, and shattering. It has a universal (grain, feed, food) direction of use. Recommended zones for cultivation are the Steppe, Forest-Steppe, and Polissya.

The soybean cultivation technology is generally accepted for the zone, except for the studied techniques. The establishment and conduct of experiments were carried out according to field research methodology.

The meteorological characteristics of the research were characterized by variability over the years, allowing for a reliable assessment of the factors studied under various weather conditions.

The weather conditions were favorable in 2021, providing sufficient moisture levels during the soybean growing season. The years 2019, 2022, and 2023 were insufficiently favorable, especially in the early stages of soybean growth and development in terms of moisture, while 2021 was excessively wet. The weather conditions in 2020 were unfavorable.

Therefore, the weather conditions during the years of the research were mostly not sufficiently favorable for achieving high soybean productivity indicators.

Results and discussion. In the conditions of the Ukrainian Steppe, soybean yield significantly varies depending on the weather and climatic conditions during the vegetation period. However, the average indicators obtained from the results of five years of research indicate that the choice of predecessor and fertilization system are factors that influence the crop's productivity.

The data presented in Table 1 show that the average soybean yield based on the studied predecessors was within a significant difference range, 1.67 t/ha, 1.81 t/ha, and 1.79 t/ha (LSD05 for factor A = 0.15 t/ha), with the lowest yield observed for the winter wheat predecessor.

Table 1

Soybean yield depending on predecessor and fertilization system

Predecessors (factor A)	Fertilization system (factor B)	Average 2019–2023	Difference, factor A		Difference, factor B	
			t/ha	%	t/ha	%
Winter wheat	Without fertilizers	1.32	–	–	–	–
	Mineral	1.71	–	–	0.39	29.4
	Organo-mineral	1.99	–	–	0.67	51.1
	Average	1.67	–	–	–	–
Corn for grain	Without fertilizers	1.45	0.13	10.2	–	–
	Mineral	1.85	0.14	8.2	0.39	27.1
	Organo-mineral	2.14	0.15	7.4	0.69	47.3
	Average	1.81	0.14		–	–
Soybean	Without fertilizers	1.48	0.16	12.3	–	–
	Mineral	1.87	0.17	9.7	0.39	26.5
	Organo-mineral	2.02	0.02	1.1	0.53	36.0
	Average	1.79	0.12		–	–
LSD05, t/ha	Factor A = 0.15; Factor B = 0.13; Factors AB = 0.29					

Against the background of natural plant nutrition without fertilizer application, a significant increase in soybean grain yield was observed in repeated soybean sowings, at 1.48 t/ha, with a yield increase by predecessor factor of 0.16 t/ha. The harvest from the corn predecessor (1.45 t/ha) was slightly higher compared to the variant where soybeans were grown after winter wheat (1.32 t/ha), but the difference in these indicators was within the LSD range.

Thus, for predecessors such as winter wheat and corn, soybean yield was at a significantly different level, with a significant yield increase observed only in repeated soybean sowings, +0.16 t/ha.

A more effective factor that positively influenced soybean yield in our research was the fertilization system.

The application of mineral fertilizers before soybean planting contributed to an increase in crop yield across all studied predecessors. It should be noted that the yield increase was consistent, amounting to 0.39 t/ha (LSD05 for factor B = 0.13 t/ha). However, the NPK system was most effective with the winter wheat predecessor (+29.4 % yield compared to the variant without fertilizers), and in repeated sowings, the yield increased by only 26.5 %. The highest soybean grain yield under the mineral fertilization system was obtained with the soybean predecessor (1.87 t/ha), slightly lower be the corn predecessor (1.85 t/ha), but this difference was not significant. Soybean sowings after winter wheat (1.71 t/ha) had lower yields despite the highest effectiveness of the mineral fertilization system in this variant.

Incorporating the harvest residues of the previous crop along with mineral fertilizer application provided the highest increase in soybean yield across all predecessors. Interestingly, the organo-mineral fertilization system worked most effectively with the corn predecessor, achieving a soybean yield of 2.14 t/ha, significantly higher than the yields with the winter wheat predecessors (1.99 t/ha) and soybean (2.02 t/ha) predecessors. The yield increase due to the fertilization system factor for soybean cultivation after corn was the highest at +0.69 t/ha (47.3 %), while the efficiency of the organo-mineral fertilization system was highest with the winter wheat predecessor, resulting in a 51.1 % yield increase of 0.67 t/ha.

Thus, the highest yield indicators under the organo-mineral fertilization system were achieved for soybean cultivation after corn (2.14 t/ha), with a significant decrease in yield observed by winter wheat and soybean predecessors (1.99 t/ha and 2.02 t/ha respectively).

The productivity of soybeans in terms of grain units yield, feed units, and digestible protein units is an important characteristic for this food crop with strategic significance.

The grain units yield from soybean harvest in our research ranged from 2.48 to 3.79 t/ha. On average over five years, the lowest grain units yield from soybean cultivation after winter wheat was 2.48 t/ha without fertilizer application. Repeated soybean sowings provided a significant increase in grain unit collection compared to winter wheat predecessors, with an increase of 0.30 t/ha, totaling 2.79 t/ha. Introducing corn as a predecessor for soybeans did not affect its productivity, with a grain units yield of 2.73 t/ha (LSD05 for factor A = 0.28 t/ha) (Figure 1).

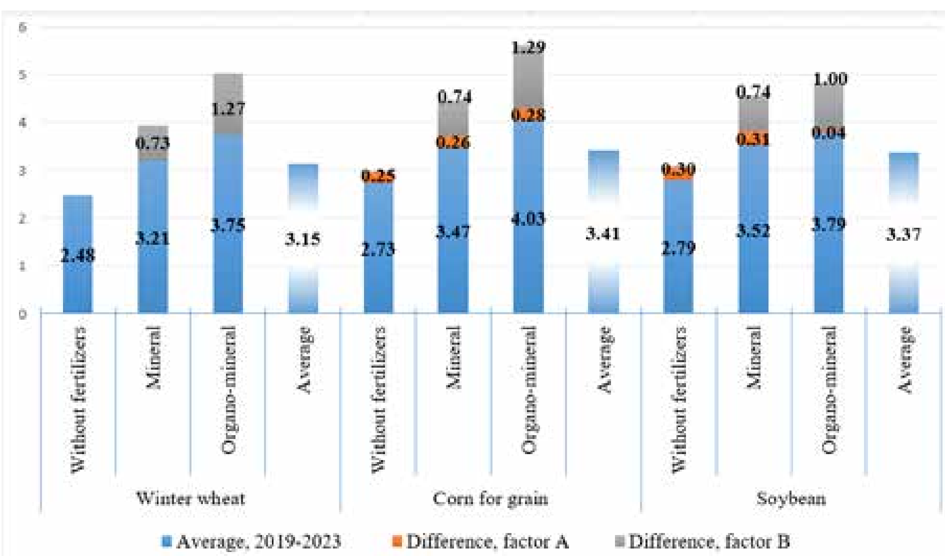

Fig. 1. Grain units yield depending on predecessor and fertilization system, t/ha, 2019–2023 (LSD05: factor A = 0.28 t/ha, factor B = 0.25 t/ha, factors AB = 0.55 t/ha)

The use of the mineral fertilization system in soybean cultivation resulted in a significant increase in grain units yield from the soybean grain harvest. Additional nutrient elements were most effectively utilized by soybean plants grown after winter wheat, leading to a 29.4 % increase in grain units yield compared to the variant without fertilizers (0.73 t/ha). Soybean cultivation after corn for grain and in repeated soybean sowings also showed an increase in grain units yield, but the predecessor factor somewhat suppressed the effectiveness of mineral fertilizers. For soybeans grown after corn for grain, the productivity of grain units yield was 8.2 %, while without fertilizer application, the yield increased by 10.2 %. In repeated soybean sowings, the predecessor factor further reduced the impact of mineral fertilizers, with a 9.7 % increase in grain units yield compared to a 12.3 % increase without fertilizers.

The highest grain units yield was achieved under the organo-mineral fertilization system. The fertilization system was most effective in increasing soybean productivity after corn for grain, with a grain units yield of 4.03 t/ha. The difference between winter wheat and soybean predecessors was significant: 3.75 t/ha and 3.79 t/ha respectively, with a LSD05 for factor of 0.25 t/ha. The highest increase in grain units yield was observed in soybean cultivation after winter wheat, with a 51.1 % increase (0.75 t/ha), while the intensity of the organo-mineral fertilization system's effect decreased slightly by corn for grain and soybean predecessors, with increases of 47.3 % (1.29 t/ha) and 36.0 % (1.00 t/ha) respectively.

Our research results confirm the trend of soybean productivity levels based on feed units yield.

Without fertilizer application, the feed units yield from soybean grain harvest did not exceed 2.40 t/ha, reaching higher levels when cultivating soybeans after corn for grain and in repeated sowings, while significantly lagging behind in winter wheat predecessors at 2.14 t/ha (Figure 2).

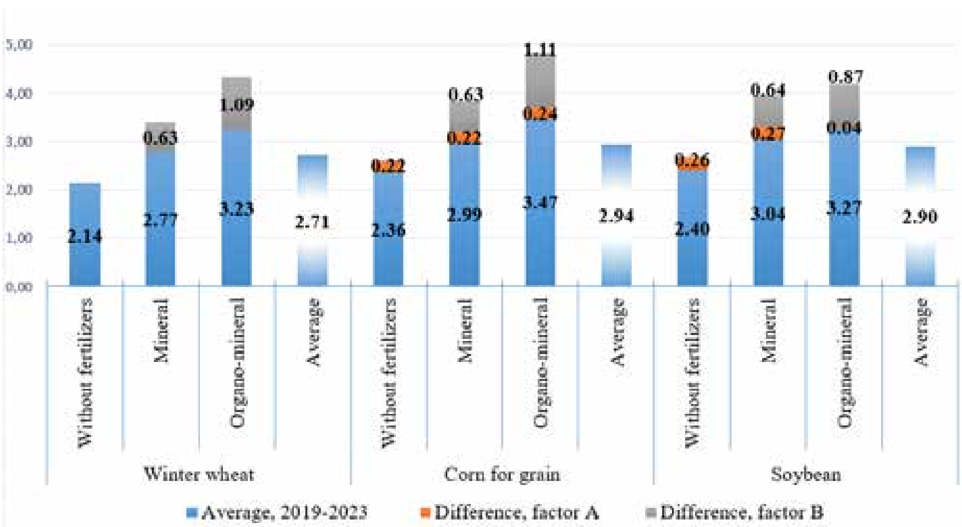

Fig. 2. Feed units yield depending on predecessor and fertilization system, t/ha, 2019–2023 (LSD05: factor A = 0.24 t/ha, factor B = 0.21 t/ha, factors AB = 0.48 t/ha)

Under the mineral fertilization system, the feed units yield increased, with the trend of predecessor factor influence maintained: higher values were observed by soybean and corn for grain predecessors (3.04 t/ha and 2.99 t/ha respectively), while lower values were recorded by winter wheat at 2.77 t/ha.

With the organo-mineral fertilization system, the feed units yield was highest: at 3.33 t/ha by winter wheat predecessors, 3.47 t/ha for corn for grain, and 3.27 t/ha for soybeans. However, there was no significant difference in the indicators based on the predecessor factor, unlike with the use of the mineral fertilization system.

Grain soybean is characterized by a high protein content, which is a valuable raw material for food production and animal feed. The digestible protein units yield is the most important indicator that determines the productivity of this crop.

Our research has shown the influence of predecessor factors and fertilization systems on the level of digestible protein units yield from soybean harvest.

The fertilization system had the most significant impact on increasing soybean productivity based on this indicator (Figure 3).

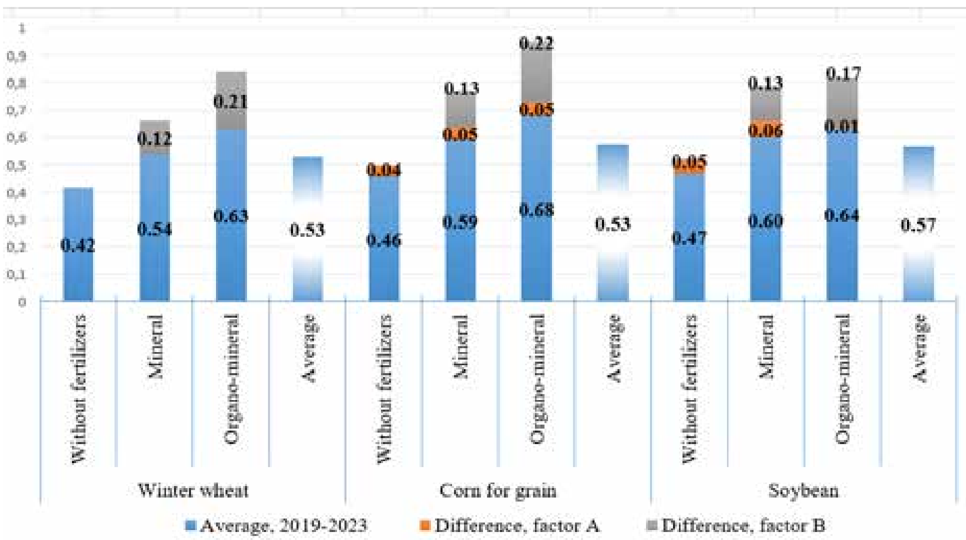

Fig. 3. Digestible protein units yield depending on predecessor and fertilization system, t/ha, 2019–2023 (LSD05: factor A = 0.05 t/ha, factor B = 0.04 t/ha, factors AB = 0.09 t/ha)

Under the organo-mineral fertilization system, the digestible protein units yield was highest across all predecessors, at 0.63–0.68 t/ha, and did not significantly differ based on factor A.

However, mineral and organic substances in the soil were most effectively utilized by soybean plants in crop rotations after winter wheat, resulting in a 51.1 % increase in protein output.

Under the mineral fertilization system, there was a significant increase in digestible protein unit yield in repeated soybean sowings and after the corn for grain predecessor compared to winter wheat (0.60 t/ha, 0.59 t/ha, 0.54 t/ha respectively, LSD05 = 0.04 t/ha).

The digestible protein units yield from soybean cultivation with the predecessors we studied, without fertilizer application, varied within a significant difference range:

0.42 t/ha, 0.46 t/ha, 0.47 t/ha for winter wheat, corn for grain and soybean predecessors respectively, with LSD05 = 0.05 t/ha.

Conclusions. In conclusion, based on five years of research, it can be concluded that fertilization systems had the most significant impact on soybean yield and productivity. Higher grain yield, grain units yield, feed units yield, and digestible protein units were achieved using the organo-mineral fertilization system after corn for grain as a predecessor: 2.14 t/ha, 4.03 t/ha, 3.47 t/ha, and 0.68 t/ha respectively. Repeated soybean sowings slightly lagged behind in these indicators, but the difference was not significant. Under the mineral fertilization system, the predecessor factor reduced the effectiveness of fertilizer action, and the difference in soybean yield and productivity based on different predecessors was significant. Therefore, the best predecessors for soybean cultivation in grain-row crop rotation with up to 60 % soybean saturation in the conditions of the northern Steppe of Ukraine were corn for grain and soybean. The use of the organo-mineral fertilization system after winter wheat as a predecessor allowed for achieving soybean crop productivity levels comparable to the best predecessors.

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АСОРТИМЕНТ ЗАСОБІВ ЗАХИСТУ КУКУРУДЗИ ВІД ШКІДЛИВИХ ОРГАНІЗМІВ В УКРАЇНІ У 2017–2018 РР.

Станкевич С.В. *– к.с.-г.н.,*
доцент кафедри зоології, ентомології, фітопатології, інтегрованого захисту і карантину рослин імені Б.М. Литвинова,
Державний біотехнологічний університет
Матвієнко В.М. *– аспірант кафедри зоології, ентомології, фітопатології, інтегрованого захисту і карантину рослин імені Б.М. Литвинова,*
Державний біотехнологічний університет
Забродіна І.В. *– к.с.-г.н.,*
доцент кафедри зоології, ентомології, фітопатології, інтегрованого захисту і карантину рослин імені Б.М. Литвинова,
Державний біотехнологічний університет

Авторами проведено дослідження структури ринку засобів захисту кукурудзи від шкідливих організмів в Україні у 2017–2018 рр. за виробником, об'єктом застосування, препаративними формами та діючою речовиною. Загалом представлено 1309 найменувань препаратів із груп інсекто-акарицидів, фунгіцидів та гербіцидів і десикантів та дозволених до використання в Україні на кукурудзі. Із них до інсекто-акарицидів належить 199 найменувань, або 15 % з усього асортименту, до фунгіцидів – 460 препаратів, або 35 %, а до гербіцидів – 650 найменувань, або 50 % всіх препаратів. ТОП-6 діючих речовин на основі яких заявляють препарати для боротьби зі шкідниками кукурудзи: альфа-циперметрин,