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PRODUCTIVITY OF SOYBEAN DEPENDS ON PREDECESSORS AND FERTILIZER SYSTEMS IN SHORT-ROTATION CROP ROTATIONS OF THE STEPPE ZONE OF UKRAINE

MASHCHENKO YU.V. – Ph.D.
orcid.org/0000-0001-7965-0193
Institute of Agriculture of the Steppe of National Academy of Agrarian Sciences
SOKOLOVSKA I.M. – Ph.D., Associate Professor
orcid.org/0000-0003-4256-8852
Kherson State Agrarian Economic University

Problem statement. Improving the soybean fertilization system and enhancing its cultivation technology in short-rotation crop rotations through optimization of organic and mineral nutrition is a significant and relevant issue in modern agriculture. Currently, the response of modern soybean varieties to the complex application of different types of fertilizers in various soil-climatic zones of Ukraine, especially considering rapid climate changes, is insufficiently studied.

Analysis of recent research and publications. Soybean is one of the most important leguminous crops in the world, providing the majority of protein and oil needs. As a strategic crop, it has quickly become part of global agriculture. In terms of economic indicators, soybean cultivation surpasses other crops in this group, and the constant demand for soybeans requires further improvement of its productivity [1, 3, 7, 10].

Important elements in soybean cultivation technology include optimizing the choice of predecessor and agronomic conditions, particularly the fertilizer system. Long-term studies on the crop demonstrate that soybean is quite demanding in these factors.

According to some researchers, the best predecessors for soybean are winter and spring cereal crops, corn for green fodder and silage. The main argument is that there is sufficient time for tillage or sowing cover crops after their harvest [12].

Repeated crops, especially in new growing regions and for consecutive years, contribute to increased soybean yield as a result of increased rhizobial bacteria population in the soil, improvement of its physical condition, nutrient regime, and weed control [9, 11, 13].

In recent years, the use of crop residues as a source of nutrients has been popularized. Due to reduced manure and organic fertilizer application, it is necessary to return plant residues to the soil to preserve its structure and prevent fertility decline. The impact of crop residues from previous crops on soybean yield has been the subject of research for many years. According to some researchers, plowing corn residues contributed to an increase in soybean yield by approximately 11.69%, resulting in an annual yield increase ranging from 2.89% to 15.94%.

Soybean is a crop that is most commonly used in crop rotation with corn, which provides advantages in rotation and increases its productivity by an average of 7.8%. Corn produces a large amount of crop residues, which should be chopped and incorporated into the soil during autumn primary tillage [4, 5].

Unlike other major agricultural crops, soybean nutrition is specific. This crop consumes more nutrients than other grains, unevenly absorbs nutrients during vegetation, is capable of nitrogen fixation from the air, and utilizes soluble compounds of phosphorus and potassium from the soil. Therefore, scientific justification for the use of cultivation technology measures that aim to increase yield and seed quality in specific soil-climatic conditions and contribute to the improvement of soybean production quality obtained from the harvest is of great importance [2, 6, 8].

Objective. To establish the dependence of soybean productivity on different predecessors and fertilizer systems in short-rotation crop rotations.

Object of research. Predecessors and fertilizer system.

Materials and methods of research. The research methods included field and laboratory-field experiments.

Field experiments were conducted from 2013 to 2022 at the Institute of Agriculture of the Steppe NAAS.

The soybean varieties Medea (2013–2020) and Zlatoslava (2021–2022) were grown in in short-rotation crop rotations with varying soybean saturation. The grain-row crop rotation with up to 40% soybean saturation included such the alternation of cultures: 1. Soybean; 2. Winter wheat; 3. Soybean; 4. Corn for grain; 5. Buckwheat. The grain-row crop rotation with up to 60% soybean saturation: 1. Soybean; 2. Winter wheat; 3. Soybean; 4. Corn for grain; 5. Soybean.

Soybean was sown from the third decade of April to the end of the first decade of May, depending on the weather conditions of the research year. The sowing rate was 800 thousand seeds per hectare. The organic-mineral fertilizer system used the by-products of the predecessor with mineral fertilizers at a rate of $N_{40}P_{40}K_{40}$, while the mineral system used only the specified amount of fertilizers.

The general soybean cultivation technology included primary soil tillage, which began with two-time harrowing of stubble. The first harrowing was done to a depth of 6–8 cm, and the second harrowing was done to a depth of 8–10 cm, 2–3 weeks after the first harrowing (when weeds appeared).

In autumn, deep plowing was carried out to a depth of 25–27 cm, which ensured loosening, turnover, and mixing of the plow layer, and allowed the incorporation of crop residues, fertilizers, as well as weed seeds and seedlings.

Pre-sowing soil preparation consisted of spring harrowing with heavy-toothed harrows and cultivation to a depth of 5–8 cm. Before pre-sowing cultivation, a soil herbicide was applied against annual grasses and broadleaf weeds. Crop care included post-sowing thinning and inter-row treatments of wide-row soybean plantings, if necessary. Pest and disease control was carried out according to existing recommendations in the region.

The experiments were conducted according to the methodology of field research.

Favorable weather conditions for achieving yields ranging from 2.26 to 2.75 t/ha were observed during the research period in 2013, 2015, 2016, 2019, and 2021. Unfavorable conditions (soybean yield below 2.0 t/ha) were observed in 2014, 2017, 2018, and 2022. Adverse weather conditions (soybean yield below 1.0 t/ha) were observed in 2020.

Research results. According to the results of the conducted ten-year research, it was established that on average, soybean yield was 2.05 t/ha after corn for grain, 2.09 t/ha after buckwheat, and 2.07 t/ha after soybean (Table 1).

Thus, comparing the effects of predecessors, it was found that soybean yield did not depend on the specified factor. Only a tendency was observed that repeated crops resulted in lower yields and after buckwheat – slightly higher yields.

Also, soybean yield for cultivation with different predecessors, relative to the fertilization system, was almost at the same level and only a tendency regarding insignificant increase or decrease in yield under different fertilization systems was observed.

Under the conditions of soybean cultivation after corn in the background of mineral and organo-mineral fertilization systems, compared to the variant without fertilizers, significant yield increases were established, which amounted to 0.21 t/ha (11.3%) and 0.37 t/ha (20.1%) respectively. Also, a significant difference in yield relative to the variant without fertilizer application was obtained when using the mineral fertilization system – 0.26 t/ha or 14.1% and organo-mineral – 0.35 t/ha or 18.7% for repeated soybean cultivation in a grain-row crop rotation.

It was found that growing soybeans after buckwheat allowed for the highest significant yield increases depending on the fertilizer system factor. The yield increase relative to the variant without fertilizers for the mineral fertilization system was 0.36 t/ha (19.9%) and for the organo-mineral system – 0.45 t/ha (24.9%).

Therefore, growing soybeans with different predecessors did not have a significant impact on its yield, however, the use of mineral and organo-mineral fertilization systems contributed to significant yield increases compared to the unfertilized variant. The highest yield increases were observed in soybean plants after buckwheat, which, compared to the variant without fertilizers, amounted to 0.36 t/ha (19.9%) for the mineral fertilization system and 0.45 t/ha (24.9%) for the organo-mineral fertilization system.

Analysis of recent research and publications on the influence of predecessors on soybean productivity show that the highest yield of this crop is obtained when it is grown after corn. Additionally, repeated crops lead to a decrease in soybean potential.

Our research has found that yield of grain units from growing soybeans after different predecessors, such as corn for grain, buckwheat, and soybean itself, was within a significant difference. It should be noted that after buckwheat, the average yield was slightly higher at 3.93 t/ha. Repeated crops of soybeans on the same field also did not decrease its productivity, with yield of grain units' output of 3.89 t/ha (Table 2).

Our research has demonstrated a significant influence of fertilization systems on crop productivity in the conditions of the northern Steppe. The highest grain units yield was obtained with the organo-mineral fertilization system after the predecessor buckwheat, at 4.27 t/ha, with a yield increase of 0.85 t/ha or 24.9%. Our research has demon-

Table 1

Soybean yield depending on predecessors and fertilization system

Predecessor, factor A	Fertilizer system, factor B	Average for 2013–2022	Difference from the predecessor, corn for grain (factor A)		Difference in fertilizer systems (factor B)	
			t/ha	%	t/ha	%
Corn for grain	Without fertilizer	1,85	–	–	–	–
	Mineral	2,06	–	–	0,21	11,3
	Organic-mineral	2,23	–	–	0,37	20,1
	Average	2,05	–	–	–	–
Buckwheat	Without fertilizer	1,82	-0,03	-1,7	–	–
	Mineral	2,18	0,12	6,3	0,36	19,9
	Organic-mineral	2,27	0,05	2,2	0,45	24,9
	Average	*2,09*	–	–	–	–
Soybean	Without fertilizer	1,86	0,01	0,5	–	–
	Mineral	2,13	0,06	3,1	0,26	14,1
	Organic-mineral	2,21	-0,01	-0,6	0,35	18,7
	Average	*2,07*	–	–	–	–
LSD_{05}	Factor A	0,13	–	–	–	–
	Factor B	0,12	–	–	–	–
	Factors AB	0,27	–	–	–	–

Table 2

Yield of grain units soybean depending on the predecessors and fertilizer system (2013–2022)

Predecessor, factor A	Fertilizer system, factor B	Average for 2013–2022	Difference from the predecessor, corn for grain (factor A)		Difference in fertilizer systems (factor B)	
			t/ha	%	t/ha	%
Corn for grain	Without fertilizer	3,48	–	–	–	–
	Mineral	3,88	–	–	0,39	11,3
	Organic-mineral	4,18	–	–	0,70	20,1
	Average	*3,85*	–	–	–	–
Buckwheat	Without fertilizer	3,42	-0,07	-1,7	–	–
	Mineral	4,10	0,22	6,3	0,68	19,9
	Organic-mineral	4,27	0,08	2,2	0,85	24,9
	Average	*3,93*	–	–	–	–
Soybean	Without fertilizer	3,50	0,02	0,5	–	–
	Mineral	4,00	0,12	3,1	0,49	14,1
	Organic-mineral	4,16	-0,03	-0,6	0,65	18,7
	Average	*3,89*	–	–	–	–
LSD_{05}	Factor A	0,25	–	–	–	–
	Factor B	0,23	–	–	–	–
	Factors AB	0,51	–	–	–	–

strated a significant influence of fertilization systems on crop productivity in the conditions of the northern Steppe. The highest grain units yield was obtained with the organo-mineral fertilization system after the predecessor buckwheat, at 4.27 t/ha, with a yield increase of 0.85 t/ha or 24.9%. Growing soybeans after soybeans resulted in a slightly lower yield of 4.16 t/ha, and was inferior to the option where the previous crop was corn for grain, but the increase in yield was significant (LSD_{05}=0.23 t/ha).

Using the mineral fertilization system, both after buckwheat and after soybeans as predecessors, the yield of grain units of soybeans was slightly lower. However, additional production due to the fertilization system was obtained at 0.68 t/ha (19.9%) and 0.49 t/ha (14.1%) respectively, which significantly exceeded the smallest difference.

The analysis of our data confirmed a similar trend in nutrient accumulation in soybean plants under the influence of the factors we studied. The highest feed unit yield was obtained with the organo-mineral fertilization system after buckwheat as a predecessor, at 3.68 t/ha. However, the variation of this indicator based on the predecessor factor was within the range of LSD_{05}=0.22 t/ha (Table 3).

The highest increase in feed units yield was obtained with the organo-mineral fertilization system in the predecessor buckwheat – 0.73 t/ha or 24.9%. In repeated crops, this indicator was lower, but no significant difference was found.

With the mineral fertilization system, a more intensive accumulation of feed units also occurred in the predecessors buckwheat and soybean, +0.58 t/ha or 19.9% and

Table 3

Yield of feed units soybean depending on the predecessors and fertilizer system (2013–2022)

Predecessor, factor A	Fertilizer system, factor B	Average for 2013–2022	Difference from the predecessor, corn for grain (factor A)		Difference in fertilizer systems (factor B)	
			t/ha	%	t/ha	%
Corn for grain	Without fertilizer	3,00	–	–	–	–
	Mineral	3,34	–	–	0,34	11,3
	Organic-mineral	3,60	–	–	0,60	20,1
	Average	*3,32*	–	–	–	–
Buckwheat	Without fertilizer	2,95	-0,06	-1,7	–	–
	Mineral	3,53	0,19	6,3	0,58	19,9
	Organic-mineral	3,68	0,07	2,2	0,73	24,9
	Average	*3,38*	–	–	–	–
Soybean	Without fertilizer	3,02	0,02	0,5	–	–
	Mineral	3,44	0,10	3,1	0,43	14,1
	Organic-mineral	3,58	-0,02	-0,6	0,56	18,7
	Average	*3,35*	–	–	–	–
LSD_{05}	Factor A	0,22	–	–	–	–
	Factor B	0,20	–	–	–	–
	Factors AB	0,44	–	–	–	–

Table 4

Yield of digestible protein units soybean depending on the predecessors and fertilizer system (2013–2022)

Predecessor, factor A	Fertilizer system, factor B	Average for 2013–2022	Difference from the predecessor, corn for grain (factor A)		Difference in fertilizer systems (factor B)	
			t/ha	%	t/ha	%
Corn for grain	Without fertilizer	0,59	–	–	–	–
	Mineral	0,66	–	–	0,07	11,3
	Organic-mineral	0,71	–	–	0,12	20,1
	Average	*0,65*	–	–	–	–
Buckwheat	Without fertilizer	0,58	-0,01	-1,7	–	–
	Mineral	0,69	0,03	5,1	0,11	19,9
	Organic-mineral	0,72	0,01	2,2	0,14	24,9
	Average	*0,66*	–	–	–	–
Soybean	Without fertilizer	0,59	0,00	0,5	–	–
	Mineral	0,68	0,02	3,1	0,08	14,1
	Organic-mineral	0,70	0,00	-0,6	0,11	18,7
	Average	*0,66*	–	–	–	–
LSD_{05}	Factor A	0,04	–	–	–	–
	Factor B	0,04	–	–	–	–
	Factors AB	0,09	–	–	–	–

+0.43 t/ha or 14.1% respectively, but no significant difference was found for the predecessor factor.

The average indicators of digestible protein output were at the level of 0.65–0.66 t/ha. A significant increase in nutrient yield was obtained when growing soybeans with the organo-mineral fertilization system for all predecessors, with the highest increase observed for the predecessor buckwheat – 0.14 t/ha or 24.9% (Table 4).

Thus, the previous crops did not have a significant impact on the accumulation of nutrients in soybean plants. However, the application of mineral fertilizers, especially in combination with nutrient residues from the previous crop, allowed for significant increases in yield. The highest yields of grain units, feed units, and digestible protein were obtained with the organo-mineral fertilization system in the predecessor buckwheat – 4.27 t/ha, 3.68 t/ha, and 0.72 t/ha respectively. However, it should be noted that productivity indicators for other predecessors were within the range of significant difference.

The highest increases in organic matter yield were also obtained with the organo-mineral fertilization system in the predecessor buckwheat – 0.85 t/ha (24.9%) grains, 0.73 t/ha (24.9%) feed units, and 0.14 t/ha (24.9%) digestible protein units.

When growing soybeans after soybeans, harvest of additional products was at the level of 0.49 t/ha grain units, 0.43 t/ha feed units, and 0.08 t/ha digestible protein units for the mineral fertilization system, and 0.65 t/ha, 0.56 t/ha, and 0.11 t/ha for the organo-mineral fertilization system respectively. The productivity of repeated soybean crops was not inferior to those grown after corn and buckwheat predecessors, with indicators within the range of significant difference.

Discussion. According to many researchers, corn and cereals are the best predecessors for soybean cultivation with high yield and productivity indicators. Our research has shown that introducing another field of soybeans or buckwheat into a short rotation crop sequence allows for the preservation of the crop's potential. The quantity and quality of production from successive soybean or buckwheat crops are not inferior to those harvested from crops with corn as the predecessor. Additionally, buckwheat is a valuable predecessor that reduces weediness in fields and improves the physical properties and phytosanitary condition of the soil. Besides, including soybeans in crop rotations contributes to nitrogen accumulation, improvement of soil structure, and fertility.

Conclusions:

1. Cultivating soybeans after corn, buckwheat, and soybean predecessors did not have a significant impact on soybean yield, with only a tendency for lower yields after repeated soybean cultivation and slightly higher yields after the buckwheat predecessor.
2. Soybean yield under different predecessors and fertilization systems was almost at the same level, with only a slight tendency for yield increase or decrease under different fertilization systems.
3. The use of mineral and organo-mineral fertilization systems resulted in significant yield increases compared to unfertilized variants for all investigated predecessors. The highest yield increases were observed after the buckwheat predecessor, with 0.36 t/ha (19.9%) for the mineral fertilization system and 0.45 t/ha (24.9%) for the organo-mineral fertilization system.
4. The previous crop did not significantly affect productivity indicators of soybeans. Higher nutrient outputs were obtained when soybeans were grown after buckwheat – 4.27 t/ha grain units, 3.38 t/ha feed units, and 0.66 t/ha digestible protein units.
5. Significant increases in soybean productivity were achieved through the use of fertilization systems. The highest increases in grain units, feed units, and digestible protein units were observed after the buckwheat predecessor with the organo-mineral fertilization system – 0.85 t/ha (24.9%), 0.73 t/ha (24.9%), and 0.14 t/ha (24.9%) respectively.
6. Successive soybean crops were not inferior in productivity to those grown after corn and buckwheat predecessors.

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Mashchenko Yu.V., Sokolovska I.M. Productivity of soybean depends on predecessors and fertilizer systems in short-rotation crop rotations of the Steppe zone of Ukraine

Important elements in soybean cultivation technology include optimizing the choice of predecessor and agronomic conditions, particularly fertilization systems. However, there is still limited research on the response of modern soybean varieties to different fertilizer types in various soil-climatic zones of Ukraine, especially considering climate change.

Therefore, it is important to scientifically justify the use of technological measures to increase soybean yield and seed quality in specific soil-climatic conditions and improve the quality of soybean products obtained from the harvest.

Our research aimed to determine the dependence of soybean productivity on different predecessors, and fertilization in short-rotation crop rotations.

Field studies were conducted from 2013 to 2022 at the Institute of Agriculture of the Steppe National Academy of Agrarian Sciences. Soybeans of the Medea variety (2013–2020) and Zlatoslava variety (2021–2022) of early maturity group were grown in short rotation grain-row crop rotations with varying soybean saturation.

Cultivating soybeans after corn, buckwheat, and soybean predecessors did not have a significant impact on soybean yield, except for a tendency for lower yields after repeated soybean cultivation and slightly higher yields after the buckwheat predecessor.

The use of mineral and organo-mineral fertilization systems resulted in significant yield increases for all investigated predecessors. The highest yield increases were observed after the buckwheat predecessor, with 0.36 t/ha (19.9%) for the mineral fertilization system and 0.45 t/ha (24.9%) for the organo-mineral fertilization system.

The previous crop did not significantly affect productivity indicators. Higher nutrient outputs were obtained when soybeans were grown after buckwheat – 4.27 t/ha grain units, 3.38 t/ha feed units, and 0.66 t/ha digestible protein units.

Significant increases in soybean productivity were achieved through the use of fertilization systems. The highest increases in grain units, feed units, and digestible protein units were observed after the buckwheat predecessor with the organo-mineral fertilization system – 0.85 t/ha (24.9%), 0.73 t/ha (24.9%), and 0.14 t/ha (24.9%) respectively. Successive soybean crops were not inferior in productivity to those grown after corn and buckwheat predecessors.

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

Мащенко Ю.В., Соколовська І.М. Продуктивність сої залежно від попередників та системи удобрення в сівозмінах короткої ротації Степової зони України

Важливими елементами в технології вирощування сої є оптимізація вибору попередника та агротехнічних умов вирощування, зокрема системи удобрення, а багаторічні дослідження культури доводять, що соя досить вимоглива до цих факторів. На сьогоднішній день недостатньо вивчена реакція сучасних сортів сої на комплексне застосування різних видів добрив у різних ґрунтово-кліматичних зонах України, особливо враховуючи швидкі зміни клімату.

Тому важливого значення в умовах сьогодення набуває наукове обґрунтування використання технологічних заходів вирощування культури, які повинні спрямовуватися на підвищення врожайності і якості насіння в конкретних ґрунтово-кліматичних умовах і сприяти підвищенню якості продукції, отриманої з урожаю сої.

Метою наших досліджень було встановити залежність рівня продуктивності сої за її вирощування по різних попередниках, в сівозмінах короткої ротації та від систем удобрення.

Польові дослідження проводилися протягом 2013–2022 рр. в лабораторії землеробства Інституту сільського господарства Степу НААН. Сою сортів Медея (2013–2020 рр.) та Златослава (2021–2022 рр.) ранньої групи стиглості вирощували у короткоротаційних зерно-просапних сівозмінах з різним насиченням соєю.

Вирощування сої по попередниках кукурудза на зерно, гречка та соя не мало істотного впливу на урожайність сої, встановлено лише тенденцію, що повторне вирощування сої призводило до отримання меншої врожайності а після попередника гречка – сприяло отриманню дещо більшого рівня врожайності.

Використання мінеральної та органо-мінеральної систем удобрення сприяло отриманню істотних прибавок врожайності за всіх досліджуваних попередників. Найбільші прибавки були по попереднику гречка і становили 0,36 т/га (19,9%) за мінеральної системи удобрення та 0,45 т/га (24,9%) – за органо-мінеральної системи удобрення.

Попередня культура при вирощуванні сої істотно не впливала на показники продуктивності. Більший вихід поживних речовин отримали за вирощування сої після гречки – 4,27 т/га зернових, 3,38 т/га – кормових одиниць, 0,66 т/га – перетравного протеїну.

Найбільший показників продуктивності сої був по попереднику гречка за органо-мінеральною системою удобрення – 0,85 т/га (24,9%), 0,73 т/га (24,9%), 0,14 т/га (24,9%) відповідно. Повторні посіви сої не поступалися за продуктивністю тим, що вирощувалися по попередниках кукурудза на зерно та гречка.

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