

**PRODUCTIVITY OF SOYBEAN IN VARIOUS CROP ROTATIONS WITH ORGANO-MINERAL FERTILISATION IN THE LEFT BANK FOREST-STEPPE OF UKRAINE**

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**Topicality.** In the context of the economic and environmental crisis, efficient utilisation of land resources, optimisation of the structure of agricultural areas in all natural and climatic zones, considering the particular characteristics of each region, and environmental conservation are important factors for sustainable development of agricultural production. Crop rotations should be dynamic, combined and intensive, and their implementation should always be based on scientific justification. **Purpose.** To determine the influence of the structure, set and arrangement of field crops in various crop rotations on the total productivity, yield and seed quality of soybeans. **Methods.** The research was conducted in the subzone of unstable moistening of the Left-Bank Forest-Steppe of Ukraine on typical low-humus chernozem at the Panfily Research Station of the National Research Centre "Institute of Agriculture NAAS of Ukraine". Soybeans were grown in 6–8-field crop rotations under an organic-mineral fertilisation system to study the influence of predecessors on productivity, yield and seed quality. The crop cultivation technology in the experiment is generally accepted and recommended for the research zone. **Methods used:** long-term field, laboratory-field, laboratory (chemical, physicochemical), mathematical and statistical. **Results.** The long-term stationary field experiment on the study of crop rotations, which was established in 2001, convincingly proves that 6–8-field crop rotations with proportion of soybeans from 12.5 to 16.7 % were highly effective in this zone over 2016–2020. The soybean seed yield, which was grown after buckwheat, winter and spring wheat as predecessors and the corresponding crop set in crop rotations, was in the range of 2.92–3.47 t/ha with oil content in seeds of 20.7–21.5 %. The economic efficiency of soybean cultivation in the structure of various crop rotations was as follows: net operating profit – 12.55–16.76 thousand UAH/ha at a level of profitability – 116–152 %. **Conclusions.** It was found that the most productive in the Left-Bank Forest-Steppe zone was a 6-field crop rotation with proportion of soybean of up to 16.7 % (soybean – winter wheat – sugar beet – spring barley – maize for grain – buckwheat) under the organic-mineral fertilisation system (by-products of the predecessor +  $N_0P_{40}K_{40}$ ). The yield per 1 ha of arable land was 4.79 t of fodder units and 1.01 t of digestible protein at a net operating profit of 16.76 thsd UAH/ha and a profitability of 152 %.

**Key words:** crop, crop rotation, yield, fodder units, crude protein, oil content, profitability, net operating profit

**Introduction.** Increasing crop production has been and remains the priority at any stage of agricultural development, and a scientifically based farming system, with crop rotation as its main component, is aimed at solving this problem. At the current stage of development of the agro-industrial complex, only a high level of farming standards is the basis for the production of competitive agricultural products.

Crop rotation is crucial component of mo-

dern agriculture as it is based on the biological characteristics of field crops. Therefore, a properly designed and implemented crop rotation is essential for improving farming standards, restoring and enhancing soil fertility, increasing crop yield and increasing the profitability of agriculture.

Soybeans (*Glycine hispida* (Moench.) Maxim.) are one of the oldest crops used for food, fodder, technical and medical purposes.

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It was introduced from China to Japan in the 7<sup>th</sup> century, and soybeans began to be sown in Europe only in the 17<sup>th</sup> century [1].

Soybeans are particularly valuable due to their high content of complete protein, which is easily digested by the human body and animals. Soybean seeds contain 35–52 % of complete amino acid protein, 17–27 % of high-quality vegetable oil, 24 % of carbohydrates, 5 % of ash elements, various enzymes, vitamins (A, B, C, B, E) and other organic and inorganic compounds [2]. It provides 20 % of the global protein resources [1].

Soybeans are an important industrial crop and a valuable predecessor for various agricultural crops due to the biological nitrogen fixation of atmospheric molecular nitrogen. It can also be used as a green manure crop. For fodder purposes, soybean green mass is used for the production of silage, haylage, grass meal, pellets, and less often of hay. It was found that 100 kg of soybean green mass contains 21 fodder units and 3.5 kg of digestible protein [3].

Ukraine is the largest soybean producer in Europe: over the period 1990–2021, its sown area increased from 75–80 thousand hectares to 2.28 million hectares [4]. In the ranking of major soybean producers, Ukraine ranks first in Europe and eighth to tenth in the world [5].

The main areas under soybean crops (about 80 %) are located in the Steppe and Forest-Steppe zones of Ukraine. New early- and mid-ripening soybean varieties developed by agricultural scientists in recent years have a shorter ripening period and produce high grain yields of 2.0–2.5 t/ha, enabling their cultivation in the Polissia region of Ukraine [6].

The best predecessors for soybeans are winter and spring spiked cereals, maize, vegetables, potatoes, etc. [2].

Among the many agronomic techniques that ensure an adequate level of productivity of high-quality crops, crop rotation plays an important role. Market conditions of farming require such crop rotations that would increase the productivity of all field crops, contribute to the stabilisation and restoration of soil fertility, improve the phytosanitary condition of agricultural areas and ensure environmental safety. [7–10].

The issue of crops arrangement in crop rotations cannot be neglected due to its importance in terms of environmental safety of agri-

culture and preservation of the natural environment (agro-landscapes). And in this context, the development of domestic agriculture in the system of the national economic complex remains the highest priority, competitive in meeting human needs for food. Therefore, the study of the effect of crop rotation factors and organic-mineral fertilisation on soybean productivity and seed quality in the conditions of the Left Bank Forest-Steppe is relevant.

The study was aimed at determining the influence of fertilisation system, predecessors, saturation and arrangement of crop rotations with soybean on productivity and economic efficiency of soybean cultivation in the conditions of the Left-Bank Forest-Steppe.

**Materials and Methods.** The research on the effect of predecessors and fertilisation system on the productivity, yield and quality of soybean seeds in various crop rotations was conducted in the subzone of unstable moistening of the Left Bank Forest-Steppe of Ukraine on the low-humus coarse-loamy chernozem of the Panfyly Research Station of the National Research Centre "Institute of Agriculture NAAS" in a long-term field stationary experiment during 2016–2020. The humus content in the topsoil layer is 3.08–3.15 %, in the subsoil layer – 2.72–2.90 %. The soil is characterised by a high phosphorus content of 233–270 mg/kg in the topsoil and 227–270 mg/kg in the subsoil, and a high and medium exchangeable potassium content of 80–100 mg/kg. The reaction of the soil solution is slightly acidic, the saturation level of the of the soil adsorption complex with bases is high (85–99 %). The average annual precipitation on the area of the experimental station ranges from 250–670 mm (average value of 442 mm), which corresponds to the conditions of Forest-Steppe subzone with unstable moistening.

The sown area of the plot was 90 m<sup>2</sup>, and the registration area was 40 m<sup>2</sup>. The experiment was repeated three times. Arrangement of the plots was randomised.

The cultivation technology of agricultural crops in the experiment is generally accepted for the area under study.

Soybeans were grown in a six-field crop rotation: soybeans – winter wheat – sugar beet – spring barley – maize for grain – buckwheat, and buckwheat – winter wheat – soybeans –

spring wheat – winter rye – spring barley; in a 7-field rotation: winter rape – winter wheat – sunflower – spring wheat – soybeans – winter wheat – spring barley; and in an 8-field rotation: (maize for green fodder – winter wheat – sunflower – spring wheat – soybeans – winter rye – oats – spring barley) under intensification of the organo-mineral system (by-products of the predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub> per 1 ha of crop rotation area) with the introduction of soil-applied and post-emergent herbicides for the crop.

Research methods include field, laboratory and field, greenhouse experiments, laboratory research (chemical, physical and chemical), mathematical and statistical.

**Results and Discussion.** Based on the results of long-term stationary experiments in

the Forest-Steppe zone of Ukraine, the main principles of diversified (6–8-field) crop rotations were developed, considering the return periods and rotation standards for each crop. This ensures a scientifically sound set of crops, their ratio and placement after the best predecessors, which contributes to rational land use, increased soil fertility (moisture, humus, etc.), improved phytosanitary conditions, etc.

Soybeans were grown under the organo-mineral fertilisation system after the predecessors – buckwheat, winter wheat and spring wheat with crop saturation of crop rotations from 12.5 to 16.7 %. The crop yield in these crop rotations ranged from 2.92 to 3.47 t/ha, depending on the duration of crop rotation (Table 1).

The highest yield of soybean seeds

*Table 1. Yield and quality of soybean seeds in diversified crop rotations, average for 2016–2020*

Predecessor	Fertiliser rate	Yield, t/ha	Weight fraction of crude protein content in conversion to dry matter, %	Weight fraction of oil in conversion to dry matter, %
6-field crop rotation				
Buckwheat	by-product of a predecessor + N <sub>0</sub> P <sub>40</sub> K <sub>40</sub>	3.47	37.4	21.2
Winter wheat	by-product of a predecessor + N <sub>0</sub> P <sub>40</sub> K <sub>40</sub>	3.29	37.9	20.8
7-field crop rotation				
Spring wheat	by-product of a predecessor + N <sub>0</sub> P <sub>40</sub> K <sub>40</sub>	3.07	37.5	21.5
8-field crop rotation				
Spring wheat	by-product of a predecessor + N <sub>0</sub> P <sub>40</sub> K <sub>40</sub>	2.92	37.4	20.7
LSD <sub>05</sub>		0.08		

(3.47 t/ha) was obtained in a six-field crop rotation with a crop share of 16.7 % after the buckwheat, which was sown after maize for grain, which is 0.18 t/ha more than in a six-field crop rotation with the same crop share after the winter wheat (buckwheat as a predecessor). Growing soybeans in a 7-field crop rotation with a crop share of 14.3 % with spring wheat as a predecessor, sown after sunflower, reduced the yield by 0.40 and 0.22 t/ha compared to six-field crop rotations with a crop share of 16.7 %, respectively. Changing the crop share in the crop rotation from 16.7 to 12.5 % (8-field crop

rotation) resulted in a decrease in soybean seed yield, on average over five years of research, by 0.55 t/ha, and amounted to 2.92 t/ha.

It should be noted that soybean cultivation in diversified (6–7–8-field) experimental crop rotations under intensification of organo-mineral system improved the seed quality, i.e. the content of crude protein and oil in soybean seeds with the application of by-products of the predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub> was quite high, namely crude protein in 6-field crop rotation with a crop share of 16.7 % and the predecessor – winter wheat was at the level of 37.9 %, which is 0.4

and 0.5 % more than when it was grown in 7-field (with a crop share of 14.3 %) and 8-field (with a crop share of 12.5 %) crop rotations, respectively, with the predecessor – spring wheat. Under different predecessors, the oil content in soybean seeds was at the level of 20.7–21.5 %, with the highest content of 21.5 % in 7-field crop rotation, which is 0.3–0.7 % higher than in 6-field crop rotation and 0.8 % higher than in 8-field crop rotation (Table 1).

Assessing crop rotation efficiency is a complex approach considering a number of indicators. To compare the productivity of crop rotations, we take into account the grain and seed production, the yield of grain, feed units and digestible protein [11]. There are different approaches to assessing crop rotation efficiency. In particular, it is proposed to use the so-called grain coefficients – the ratio of the average yield

of winter wheat to the average yield of the crop, which is estimated over several years. It is proposed to evaluate productivity in monetary terms. The global practice applies the assessment of crop rotation productivity based on conversion into grain equivalents [12]. The yield level of each crop and the crop rotation productivity generally depend on the effect of predecessors, tillage systems, fertilisation and plant protection products [13].

In 2016–2020, the productivity of soybeans grown in diversified crop rotations (6–7–8-field) with different crop saturation was characterised by quite high indicators and provided a harvest of 4.03–4.79 t of fodder units, 5.26–6.25 t of grain units, and 0.85–1.01 t of digestible protein per 1 ha of arable land (Table 2).

It should be noted that the 6-field crop ro-

**Table 2. Seed productivity of soybeans in diversified crop rotations, average for 2016-2020**

Predecessor	Output per 1 ha of arable land, t		
	fodder units	grain units	digestible protein
	6-field crop rotation ( <i>by-product of a predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub></i> )		
Buckwheat	4.79	6.25	1.01
Winter wheat	4.54	5.92	0.95
	7-field crop rotation ( <i>by-product of a predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub></i> )		
Spring wheat	4.24	5.53	0.89
	8-field crop rotation ( <i>by-product of a predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub></i> )		
Spring wheat	4.03	5.26	0.85

tation, which is 16.7 % saturated with soybeans after buckwheat, had higher harvest indicators of fodder units, grain units and digestible protein per 1 ha of arable land, where these indicators were 4.79 t of fodder units, 6.25 t of grain units and 1.01 t of digestible protein, which is higher by 0.25 t of fodder units, 0.33 t of grain units and 0.06 t of digestible protein compared to 6-field crop rotation with 16.7 % saturation after winter wheat.

Soybeans in a 7-field crop rotation, which was grown after spring wheat, with 14.3 % crop saturation, was characterised by slightly lower productivity indicators, where the yield per 1 ha of arable land was within 4.24 t of fodder units, 5.53 t of grain units and 0.89 t of digestible protein.

The 8-field crop rotation saturated with soybeans by 12.5 % ensured a yield per hectare of crop rotation area: 4.03 t of fodder units, 5.26 t of grain units and 0.85 t of digestible protein, which is 5 % less than the 7-field crop

rotation and 11–16 % less than the 6-field crop rotation.

The economic efficiency indicators of crop rotations were determined based on the preparation of technological charts, considering the costs of tillage, labour, fertilisers, seeds, plant protective products and the final production. Calculations were made based on the purchase prices for agricultural products prevailing in 2020.

The economic analysis of soybean cultivation in 6–7–8-field crop rotations showed the dependence of the obtained yield indicators on the predecessor, pre-predecessor and fertilisation, where the net operating profit, on average, for five years of research, was 12.55–16.76 thousand UAH/ha, with a profitability of 116–152 % (Table 3).

Soybeans, which were grown in a 7-field crop rotation with a crop saturation of 14.3 %, provided a net operating profit of 13.65 thou-

**Table 3. Economic efficiency indicators of soybean cultivation in diversified crop rotations, average for 2016-2020**

Predecessor	Total costs, thousand UAH	Gross product value, thousand UAH	Cost value of 1 tonne of harvest, thousand UAH	Profit, thousand UAH/ha	Profitability, %
6-field crop rotation ( <i>by-product of a predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub></i> )					
Buckwheat	11.01	27.76	3.14	16.76	152
Winter wheat	11.02	26.32	3.15	15.30	139
7-field crop rotation ( <i>by-product of a predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub></i> )					
Spring wheat	10.91	24.56	3.12	13.65	125
8-field crop rotation ( <i>by-product of a predecessor + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub></i> )					
Spring wheat	10.81	23.36	3.09	12.55	116

sand UAH per 1 ha of crop rotation area with a profitability of 125 % after the spring wheat and before the sunflower. The gross production value was in the range of 24.56 thousand UAH. Production of soybean seeds in 8-field crop rotation with a crop saturation of 12.5 % after spring wheat and before the sunflower provided a profit of 12.55 thousand UAH/ha at a profitability of 116 %, while the costs amounted to 10.81 thousand UAH, and the cost of 1 t of yield was 3.09 thousand UAH.

The highest profitability was achieved by growing soybeans in 6-field crop rotations with a crop share of 16.7 % after buckwheat and winter wheat. Net operating profit of soybean seed production after winter wheat and before buckwheat was 15.30 thousand UAH/ha with a profitability level of 139 % and total costs of 11.02 thousand UAH. Cultivation of soybeans after buckwheat and maize for grain as a predecessors was the most profitable, with a net operating profit of 16.76 thousand UAH/ha and a profitability of 152 %. The gross production value was 27.76 thousand UAH, while the cost of 1 t of crop was 3.14 thousand UAH. Cultivation of the crop in this crop rotation increased the profit by 3.11 thousand UAH/ha compared to 7-field, and by 4.21 thousand UAH/ha compared to 8-field crop rotation.

**Conclusions.** It was established that in the subzone of unstable moistening of the Left Bank Forest-Steppe of Ukraine on typical chernozems, soybean cultivation in 6–7–8-field crop rotations after buckwheat, winter and spring wheat

with crop saturation from 12.5 to 16.7 % under the organic-mineral fertilisation system provided high yields, seed quality and economic efficiency.

In these crop rotations, soybean yields ranged from 2.92–3.47 t/ha. The highest seed yield (3.47 t/ha) was obtained in the 6-field crop rotation with 16.7 % crop saturation. Reducing the soybean share in the crop rotation to 12.5 % resulted in a decrease of 0.55 t/ha in crop yield over the five years of research.

The crude protein content in soybean seeds was 37.9 % when soybeans were grown in a 6-field crop rotation, as compared to other crop rotations, which is 0.4–0.5 % higher. The oil content was the highest (21.5 %) in the 7-field crop rotation.

It was found that the 6-field crop rotation with 16.7 % saturation with soybeans provided the highest yield per 1 ha of arable land: 4.79 t of fodder units, 6.25 t of grain units and 1.01 t of digestible protein, which is 11.5 % higher than the 7-field crop rotation with 14.3 % saturation, and 16 % higher than the 8-field crop rotation with 12.5 % saturation.

It was found that soybean cultivation in diversified (6–7–8-field) crop rotations was carried out with rather high total costs, which amounted to 10.81–11.02 thousand UAH per 1 ha of crop rotation area.

The most profitable was the soybean cultivation in a 6-field crop rotation with a crop saturation of 16.7 %, where the net operating profit was 16.76 thousand UAH/ha with a profitability level of 152 %.

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**Цимбал Я. С., Мартинюк І. В., Пташнік М. М., Шляхтуров Д. С., Оксимець О. Л. Продуктивність сої в різноротаційних сівозмінах Лівобережного Лісостепу України за органо-мінерального удобрення. *Зернові культури. 2023. 7 (2). 329–334.***

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**Актуальність.** В умовах економічної та екологічної кризи ефективно використання земельних ресурсів, оптимізація структури посівних площ в усіх природно-кліматичних зонах з урахуванням специфіки кожного регіону разом з охороною навколишнього середовища є важливим фактором сталого розвитку аграрного виробництва. Сівозміни мають бути динамічними, комбінованими та інтенсивними, але їх впровадження завжди потребує наукового обґрунтування. **Мета.** Встановлення впливу структури, набору та розміщення польових культур у різноротаційних сівозмінах на загальну продуктивність, врожайність і якість насіння сої. **Матеріали і методи.** Дослідження проведено в підзоні нестійкого зволоження Лівобережного Лісостепу України на чорноземі типовому малогумусному Панфільської дослідної станції ННЦ «ІЗ НААН». Сою вирощували у різноротаційних 6-8-пільних польових сівозмінах за органо-мінеральної системи удобрення з вивчення впливу попередників на продуктивність, урожайність і якість насіння. Технологія вирощування сільськогосподарських культур у досліді загальноприйнята і рекомендована для зони проведення досліджень. Методи – польові, лабораторно-польові, лабораторні (хімічні, фізико-хімічні), математично-статистичні. **Результати.** Дослідження у тривалому стаціонарному польовому досліді, який було закладено у 2001 р., з вивчення сівозмін, переконливо свідчать про те, що упродовж 2016–2020 рр. вискоєфективними в цій зоні виявилися 6-8-пільні сівозміни насичені соєю від 12,5 до 16,7 %. Урожайність насіння сої, яку вирощували після гречки, пшениці озимої та ярої, і відповідного набору культур сівозмін, була в межах: 2,92–3,47 т/га, за вмістом олії в насінні – 20,7–21,5 %. Економічна ефективність вирощування сої в структурі різноротаційних сівозмін становить: умовно чистий прибуток – 12,55–16,76 тис. грн/га рівень рентабельності – 116–152 %. **Висновки.** Встановлено, що найбільш продуктивною в зоні Лівобережного Лісостепу виявилася шестипільна сівозміна насичена соєю на 16,7 % (соя – пшениця озима – буряки цукрові – ячмінь ярий – кукурудза на зерно – гречка) за органо-мінеральної системи удобрення (побічна продукція попередника + N<sub>0</sub>P<sub>40</sub>K<sub>40</sub>). З 1 га ріллі зібрали 4,79 т кормових одиниць і 1,01 т перетравного протеїну за умовно чистого прибутку 16,76 тис. грн/га та рентабельності 152 %.

**Ключові слова:** культура, ротація, врожайність, кормові одиниці, сирий протеїн, вміст олії, рентабельність, умовно чистий прибуток