Ecologization of crop industry by introducing a bean component into the field crop rotation of Western Siberia

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Abstract. The paper studies field crop agrophytocenoses and their productivity in multi-year field experiments. Accompanying measurements and observations of crop rotations in the southern forest steppe zone of Western Siberia were carried out using the method of state crop testing and methodological instructions of B.A. Dospekhov. The soybean grain quality was determined according to GOST 10846-91 Grain and its processing products. Method of protein definition; GOST ISO 5983-2-2016 Fodder, compound feeds, compound feed raw materials. The mass fraction of nitrogen was determined and the mass fraction of crude protein was calculated. Sibiryachka soybean variety was used in crops. The experience has shown that the maximum accumulation of humus is ensured by crop rotation alternation. The use of complete fallow in rotation increases the productivity of the whole crop rotation to 2.36 t/ha with feed unit content amounting to 3.87 t/ha. Crop-replacing rotation differ from each other in productivity, however, the inclusion of oilseed crop in the scheme allowed balancing the content of feed units. The rotation of crops and the place of soybean in crop rotation significantly affected its yield. Protein accumulation does not depend on rotation and a set of precursors.

1. Introduction
Agricultural enterprises, as the elements of a complex, interrelated productive, economic, social and environmental system, shall be constantly subject to sustainable development thus ensuring environmental safety of crop cultivation. It is important to take advantage of all possibilities of rapid restoration of the structure and balance of the artificial ecosystem during long-term operation of tilled areas.

The control of mechanisms of ecosystem restoration and design of anthropogenic cenoses with specified properties is a relevant research task [1, 2]. Deep knowledge of laws, detailed study of ecosystem principles of crop rotation and cultivated land complexes will provide for direct reconstruction towards stabilization of agricultural productivity [3].

Agriculture, together with increased productivity, shall influence the optimization of all biosphere processes, especially the cycle of matter. According to the scientific community, the formation of a tilled area structure based on crop rotation leads to more ecofriendly cultivation of field crops. Researchers emphasize the importance of crop rotations in the fight against weed infestation of crops [4–6], their importance in stabilizing soil fertility [7, 8], regulation of plant productivity and the quality of products obtained from them [9].
The purpose of the study was to justify environmental measures to increase the efficiency of field crops cultivation by determining the place of the bean component (soybean) in the field crop rotation of Western Siberia.

2. Methods
The studies were carried out in multi-year field crop rotations of long-term stationary experiment in the zone of southern forest steppe of Western Siberia. Soybean as a precursor has been introduced in crop rotation since 2014. Four variants of crop rotation in the experiment are shown in the tables with results.

The experimental plot is characterized by meadow-chernozem middle loamy middle humus soil. The area under each culture in the crop rotation scheme is 0.125 hectares. The replication of the experiment – quadruple, placement – according to randomization principle. The zone technology of crop cultivation recommended by Omsk Agrarian Research Center was used [10]. The zoned varieties of field crops were used for sowing, soybean variety – Sibiryachka.

Soil samples from pre-seeding and pre-crop harvesting were examined for humus quantity using the Tyurin’s method [11]. The method of state crop testing [12] and the methodological recommendations of B.A. Dospekhov [13] served the basis for accompanying accounting and observations. Quality indicators of soybean grain in the experiment were studied by main methods [14, 15]. The variance analysis of the test data was performed using Microsoft Office Excel.

3. Results and Discussion
The paper uses data collected over five years (2015–2019) after modernization of stationary crop rotation schemes through the introduction of soybean. The content and supply of substances required by plants depends on many factors. The content of humus in soil is particularly important for chemical and biological processes.

As a result of the field experiment, it was found that during the rotation period the content of humus in the 0–40 cm soil layer depended on crop sets in crop rotations. All schemes with crop rotation alternation provided an increase of humus content from 0.39 to 0.63 %. The maximum accumulation was provided by four-field rotation soybean – wheat – barley – oat. The field with complete fallow in the crop succession resulted in a decrease of humus content in the upper soil layer by 0.48 % (Table 1).

| Crop rotation scheme                          | Humus content, % |  |
|-----------------------------------------------|------------------|---|
|                                          | beginning of rotation | end of rotation |
| soybean – wheat – barley – oat               | 5.08             | 5.71 |
| seeded fallow – wheat – soybean – oat        | 5.91             | 6.30 |
| complete fallow – winter rye – soybean – wheat – barley | 6.57             | 6.09 |
| oil seed rape – wheat – barley – soybean – wheat | 4.88             | 5.37 |

This pattern is caused by the fact that the presence of non-fallow crop rotation in agrocenoses results in better nitrogen fixation and accumulation of nitrogen in soil, and the constant presence of postharvest organic residues in soil contributes to soil humification processes. Absence or lack of organic matter inflow in complete fallow crop rotation resulted in the decrease of humus content due to its destruction during field fallowing.

Legumes, including soybeans, are known to poorly compete with plants of other families. Besides, the productivity of plant community, especially artificially created, is composed of its components. Weed vegetation has a significant impact on the growth and development of crop plants. It is important to observe the dynamics of presence and species composition of weeds. We noted that in soybean crops, the set of weed groups varies in test variants after the precursors (Table 2).
Table 2. Number and weight of weeds in soybean crops (average over 2015–2019)

| Variant            | Total weeds | Poaceae | Juvenile Dicotyledoneae | Soboliferous |
|--------------------|-------------|---------|------------------------|--------------|
| After oat          | 22/123a     | 7/20    | 10/43                  | 5/60         |
| After wheat        | 17/90       | 2/5     | 10/27                  | 5/58         |
| After winter rye   | 13/35       | 3/3     | 9/22                   | 1/10         |
| After barley       | 31/151      | 6/17    | 15/54                  | 10/80        |

*The numerator indicates the number of weeds (pcs/m²) and the denominator indicates their weight (g/m²).

In field crop rotation, the presence of a fallow segment has a major influence on the presence of weeds from classification groups. Thus, in soybean crops after winter rye and wheat placed according to fallow precursors, the total number and weight of weeds were minimal. Among them were mostly Juvenile Dicotyledoneae. In crop rotations, root sucker and Poaceae weed vegetation joined these groups of weeds. Their total weight increases by 1.7–4.3 times.

In 2019, the total soybean production in the Russian Federation reached 4.34 million tons in standard weight, which is 10% more compared to 2018, when another record was set – soybean sowing on the area of 2.78 million hectares (+141 thousand hectares to 2017). At the same time, the gross yield increased to 1.7 million tons, of which more than 40% were contributed by Siberian farmers (165 thousand tons). Soybean sowing areas in Omsk region increased from 6.7 thousand hectares in 2016 to 10.7 thousand hectares in 2018, but so far its yield is very low – from 0.82 to 0.92 t/ha [16].

In order to use soybean in optimizing and greening the structure of tilled lands, it is necessary to assess the productivity of the whole crop rotation. Over the years of our research, the results were obtained concerning the yield of grain, feed units and digestible protein (Table 3).

Table 3. Productivity of field crop rotation in the southern forest steppe of Western Siberia (2015–2019)

| Crop rotation scheme                  | Yield from 1 ha of tilled land, t |
|--------------------------------------|----------------------------------|
|                                      | grain  | feed unit | digestible protein |
| soybean – wheat – barley – oat       | 2.06   | 2.55      | 0.23               |
| seeded fallow – wheat – soybean – oat| 1.40   | 2.87      | 0.28               |
| complete fallow – winter rye – soybean – wheat – barley | 2.36 | 3.87 | 0.31 |
| oil seed rape – wheat – barley – soybean – wheat | 1.31 | 2.54 | 0.12 |

The variant of crop rotation using complete fallow in the rotation showed the best yield per hectare of the tilled land. In total, 2.36 t/ha of grain was obtained with a feed unit content of 3.87 t/ha. Crop rotation with seeded fallow was inferior to the variant with complete fallow in terms of the amount of grain by 1.7 times, the collection of feed units per ton from hectare was less.

Crop rotations significantly differ from each other in the collection of grain products. The rotation of soybean – wheat – barley – oat provided a grain yield of 2.06 tons, and the rotation of oil seed rape – wheat – barley – soybean – wheat – by 0.75 tons/ha less. However, due to the presence of oil culture in the crop rotation, the collection of feed units is at the same level – 2.54–2.55 t/ha.

The productivity of the studied crop rotations was mainly influenced by the presence of a bean segment in the scheme. It is interesting how rotation itself affected soybean productivity? The data are shown in Table 4.

Table 4. Yield and quality of soybean grain depending on diversification in crop rotation (2015–2019)

| Crop rotation scheme                  | Crop yield, t/ha |
|--------------------------------------|-----------------|
|                                      | fat  | protein |
| soybean – wheat – barley – oat       | 1.30 | 18.15   | 33.49 |
| seeded fallow – wheat – soybean – oat| 1.22 | 18.40   | 31.74 |
| complete fallow – winter rye – soybean – wheat – barley | 1.72 | 16.25 | 32.78 |
| oil seed rape – wheat – barley – soybean – wheat | 1.00 | 18.10 | 35.66 |
| LSD_{05}                             | 0.43 | 1.62 | F_{<}F_{1}}
In our research the maximum soybean harvest was formed when it was sown after winter rye in crop rotation with complete fallow and amounted to 1.72 t/ha. The protein content in the product (32.78 %) was not significantly different from other variants, the shortfall in fat in this variant averaged 11.5 %.

In the absence of a fallow precursor and short crop rotation, soybean yield was obtained at 1.3 t/ha with a protein content of 33.49 % and fat content of 18.15 %. Five-course crop rotation gave the lowest yield (1 t/ha). The conditions in the soybean field (weed infestation, nutrient supply, moisture supply) did not result in heavy yield, but the protein content of the soybean grain was on average 3 % higher. The findings confirm previous studies [17] that grain quality is poorly correlated with grain yield in all variants.

4. Conclusion
As a result of the study it can be concluded that in the forest steppe conditions of Western Siberia, ecologization of the crop production industry by keeping the bean component in zone crop rotation schemes allows stabilizing their productivity and thus sustainable development. Field crop rotations contribute to the accumulation of humus, unlike crop rotations with complete and seeded fallow. However, the phytosanitary state of agrocenoses without fallow precursor is deteriorating through the presence of soboliferous and Juvenile Dicotyledoneae weeds. Based on the results of the study, the following may be recommended to agricultural producers: to introduce the bean segment in the plant rotation link with complete fallow and winter rye to increase the productivity per hectare; in order to maintain soil fertility, to form a tilled land structure on the principle of crop rotation with mandatory inclusion of legumes.

Acknowledgments
The study of field crop rotations was carried out at Omsk Agrarian Research Center within the budgetary project Development of new schemes of field crop rotation against the application of intensification elements for the systems of adaptive and landscape agriculture in the forest-steppe of Western Siberia (Section 2, subsection 4 of the Fundamental Research Program of the State Academy for 2013-2020, No. 0797-2014-0003). In preparing the publication, we used the results of biochemical analysis of plant samples performed at the Central Educational and Scientific Laboratory of Omsk State Agrarian University named after P.A. Stolypin.

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