Agrophysical properties of soil and yield of spring barley for various predecessors and mineral fertilizers in the Central Black Earth Region

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Abstract. The research is devoted to the study of the influence of precursors and mineral fertilizers, applied in various doses, on the agrophysical properties of the soil, the value of the grain yield of spring barley in the soil and climatic conditions of the Central Black Earth region. The field experiment was based on the long-term hospital of Belgorod State Agrarian University named after V. Ya. Gorin. As an object, the variety of spring barley Knyazich, recommended for the region, was chosen. The soil of the experimental plot is typical chernozem, medium loamy granulometric composition on loess-like loam. The experiment scheme (4×4) provided for the study of four gradations of factor A (predecessors: corn for grain - control, sunflower, sugar beet, soybeans) and factor B (doses of mineral fertilizers: N10P10K10 - control, N30P30K30, N50P50K50, N70P70K70). Growth and development of spring barley plants in 2018-2020 took place in meteorological conditions characterized as arid with a predominance of elevated temperatures and insufficient precipitation during the critical phases of plant vegetation. The results of field experiments established that the water and agrophysical properties (density and structural-aggregate composition) of the soil under the influence of previous crops approached the optimal values and changed insignificantly. Increased doses of mineral fertilizers had a positive effect on the value of the yield of barley grain according to the studied predecessors. The highest grain yield over the years of research was obtained at high N50P50K50 and intensive N70P70K70 backgrounds for the predecessors of soybeans and sugar beets and amounted to 5.48 and 5.03 t/ha and 5.33 and 5.32 t/ha, respectively. This was higher than the control of corn for grain 0.82 and 0.37 t/ha and 0.62 and 0.61 t/ha, while for sunflower it decreased to 4.06 and 4.71 t/ha and was at the level with the control.

1. Introduction
The production of spring barley (Hordeum sativum L.) among other grain crops in the world agriculture ranks fourth after wheat, rice and corn. The share of spring barley in the Russian Federation is 13%, in the Central Black Earth region - 17% of all grain crops [1, 2].

One of the most important techniques in the cultivation of spring barley is the correct selection of predecessors for specific soil, climatic and production conditions and their influence on the formation of its yield. When choosing them, it is necessary to be guided by the degree and nature of the impact on the subsequent culture, which is determined by the morphological and biological characteristics of plants [3].
The predecessors affect the subsequent culture through the following factors: plant residues they leave, changes in soil density and duty cycle, harvesting times, and their effect on the phytosanitary state of the soil. Soil density changes both through anthropogenic factors, mechanical action, loosening and compaction, and under the action of natural moisture, drying, freezing and thawing. All these changes affect the growth and development of plants [4].

Soil density is the most important indicator of soil fertility, the duty cycle and aeration, water and air regime, microbiological activity and the rate of mineralization of non-humified plant residues depend on it. The main reason for the decrease in spring barley yields during soil compaction is the deterioration of conditions for the formation of a powerful root system and its vigorous activity. The culture, as well as its predecessors, create different conditions for the formation of soil density and, therefore, to a greater extent, determine its yield [5].

An important factor in soil fertility is also its structure. It is in the structural soil that optimal conditions for water, air and thermal regimes are created. This, in turn, causes a high porosity, the absence of surface runoff and, as a rule, the exclusion of erosion processes [6].

In the formation of the yield of spring ear crops, special importance is attached to the content of productive moisture in the soil, which is often a limiting factor in the Central Black Earth Region. For its more efficient use by plants, mineral fertilizers are used, which save 23-30% moisture to create 1 ton of grain. Despite the fact that the doses of mineral fertilizers are a limiting factor, according to the results of studies by foreign authors, the pre-sowing application of nitrogen fertilizers led to a slight increase in the yield of grain and straw of spring barley [7, 8].

High yields of barley can be obtained by placing it in a field crop rotation after perennial grasses, buckwheat, rapeseed, row crops, especially after maize for silage and grain, as well as after potatoes. Previous crops for barley should well clear the field of weeds, not accumulate infections, especially root rot, and have a beneficial effect on the physical properties of the soil. In the Central Black Earth Region, the main predecessors of spring barley are sugar beet, corn for silage and grain, sunflower [1].

This served as the basis for studies to study the influence of predecessors and mineral fertilizers on the water and agrophysical properties of the soil, the yield of spring barley in the soil and climatic conditions of the Central Black Earth Region.

2. Materials and methods

Studies to study the effect of predecessors and mineral fertilizers on the agrophysical properties of the soil and the productivity of spring barley were carried out in 2018-2020, in the long-term stationary field experience of Belgorod State Agrarian University with a predominance of arid weather conditions.

The experimental plot is represented by typical medium-thick medium-loamy chernozem on loess-like loam with a humus content in the arable layer of 4.9 %, hydrolyzable nitrogen - 156.5 mg/kg, mobile phosphorus - 228.4 mg/kg, exchangeable potassium - 181.3 mg/kg, exchangeable magnesium - 12.8 mg/kg, mobile sulfur - 2.3 mg/kg soil, pH of the salt extract - 6.0, hydrolytic acidity - 2.2 mg-eq./100 g of soil. The amount of absorbed bases is 39.1 mg-eq./100 g of soil.

The object of research was a zoned high-yielding mid-season variety of spring malting barley Knyazhich.

The area of the accounting plot in the experiment was 50 m², the sowing area was 51 m². The plots were placed systematically in triplicate. The sowing of the crop was carried out with a grain seeder SZ-3.6 with a row spacing of 15 cm and a sowing depth of 4-5 cm. The seeding rate was 5.0 million viable seeds per hectare.

Field experience is two-factor: factor A - predecessors, factor B - application rates of mineral fertilizers. Factor A had four grades: 1 - corn for grain (control), 2 - sunflower, 3 - sugar beets, 4 - soy. The second factor also had four gradations: 1 - N₁₀P₁₀K₁₀ (low background) - control, 2 - N₃₀P₃₀K₃₀ (medium background), 3 - N₅₀P₅₀K₅₀ (high background), 4 - N₇₀P₇₀K₇₀ (intense background).

The counts and observations were carried out according to generally accepted methods. The determination of the main phenological phases of plant growth and development was carried out
visually for all variants of the experiment in two non-adjacent repetitions. The reserves of productive moisture in the soil were determined by the thermostat-weight method. Macro-aggregate analysis of the soil was carried out according to the method of N.I. Savinova. Soil density was determined by the cutting ring method developed by N.A/ Kachinsky. Mathematical processing of the data was carried out by the method of analysis of variance.

After harvesting the predecessors and post-harvest disking, according to the experiment scheme, mineral fertilizers were applied in the form of azofoska, and then the main soil cultivation was carried out with a disc harrow DM-4×4 to a depth of 14-16 cm. In the spring, after the snow melted, when the soil was physically ripe, moisture was closed by looping the unit from harrows SHB-2.5 and VNIS-R, as well as plumes from metal corners. Presowing soil preparation was carried out using VNIS-R tine harrows complete with a leveling chain. Sowing of spring barley was carried out with a grain seeder SZ-3.6 with simultaneous introduction of N\textsubscript{10}P\textsubscript{10}K\textsubscript{10} azophoska.

The protection of spring barley crops from weeds was carried out in the tillering phase of plants in 2018 on May 11 with the herbicide Ballerina New (0.4 l/ha). In 2019 - on May 15 the crops of the precursors of soybeans and sugar beets were treated with a tank mixture consisting of Grand Prix herbicides (25 g/ha) and Eraser Extra (0.8 l/ha) with the addition of the surfactant Lip (0.2 l/ha). For the predecessors sunflower and corn for grain, we used Svarog preparations (0.5 l/ha) and on May 23 Eraser Extra (0.8 l/ha) in accordance with the species composition of weeds. In 2020, on May 14, spring barley was treated with Agrokson (0.8 l/ha) and Eraser Extra (1.0 l/ha) herbicides together with Racurs fungicide (0.4 l/ha).

Meteorological conditions for the growing seasons 2018-2020 differed from the average long-term values typical for the region and were characterized by insufficient precipitation and excess heat during the growth and development of spring barley plants.

3. Results and discussion
Water is an important stably influencing natural factor on which the growth and development of plants, the productivity of grain crops, including spring barley, depend. In the Central Black Earth Region with unstable moisture, moisture is in short supply of all the main factors of plant life that determine the productivity of grain crops. Therefore, to regulate the water regime of the soil, it is necessary to scientifically approach the selection of precursors and doses of mineral fertilizers.

Taking into account the moisture, morphology and biology of spring barley, we conducted studies on the effect of various precursors and doses of mineral fertilizers on the agrophysical properties of chernozem soil. In combination with the introduction of various doses of mineral fertilizers, the traditional row-crop predecessors of corn for grain, sunflower, sugar beets were studied in comparison with the new cereal legume predecessor soy and their effect on the water and agrophysical properties of the soil, the productivity of spring barley crops.

As a result of field research carried out in 2018-2020 it was found that under barley the change in the reserves of productive moisture was uneven and rather stable over the years. For the period of sowing spring barley in the 0-30 cm soil layer, the reserves of productive moisture were at a good level of 44-46 mm for all studied predecessors, in the 0-100 cm layer at a high 160-167 mm for grain corn (control variant) and sunflower and slightly below 160 mm for sugar beets and soybeans (table 1).

By the end of the growing season of spring barley, the reserves of productive moisture significantly decreased in the soil layer from 0-30 cm to 33-37 mm and 0-100 cm to 111-120 mm, especially on the options for sugar beets and soybeans with a high yield of barley grain, the crops of which more actively used moisture.

Soil density also plays an important role in the growing season of spring barley plants, determines the water-air and thermal regimes. When the arable layer is overcompacted, the soil allows less water to pass through, and when it is loosened, it increases its convection-diffuse evaporation. Therefore, the study of the bulk density is of great importance for the correct solution of issues associated with the choice of precursors and doses of mineral fertilizers. The optimum soil density for spring barley is 1.1-
1.2 g/cm³. In studies on the effect of precursors and mineral fertilizers on the productivity of spring barley in arid conditions 2018-2020 soil density differed slightly. For the sowing period in the 0-30 cm layer, it varied within 0.90-0.94 g/cm³ and corresponded to the loose soil composition, and during harvesting it increased to the optimal 1.03-1.10 (table 2).

### Table 1. Reserves of productive moisture in the soil for the period of sowing and harvesting spring barley, mm (2018-2020)

| Predecessors (factor A) | Mineral nutrition background (factor B) | For the sowing period | For the cleaning period |
|-------------------------|----------------------------------------|-----------------------|------------------------|
|                         |                                        | 0-30 | 0-100 | 0-30 | 0-100 |
| Corn for grain (control)| N₀₁₀P₀₁₀K₀₁₀ (control)                | 48   | 166   | 31   | 119   |
|                         | N₀₃₀P₀₃₀K₀₃₀                          | 44   | 161   | 33   | 119   |
|                         | N₀₅₀P₀₅₀K₀₅₀                          | 46   | 164   | 33   | 119   |
|                         | N₀₇₀P₀₇₀K₀₇₀                          | 47   | 172   | 36   | 123   |
|                         | Average                               | **46** | **166** | **33** | **120** |
| Sunflower               | N₀₅₀P₀₅₀K₀₅₀                          | 45   | 165   | 39   | 122   |
|                         | N₀₇₀P₀₇₀K₀₇₀                          | 48   | 172   | 39   | 120   |
|                         | Average                               | **46** | **167** | **37** | **120** |
| Sugar beets             | N₀₅₀P₀₅₀K₀₅₀                          | 43   | 160   | 39   | 117   |
|                         | N₀₇₀P₀₇₀K₀₇₀                          | 49   | 166   | 39   | 116   |
|                         | Average                               | **44** | **160** | **37** | **116** |
| Soy                     | N₀₅₀P₀₅₀K₀₅₀                          | 44   | 155   | 30   | 111   |
|                         | N₀₇₀P₀₇₀K₀₇₀                          | 46   | 158   | 35   | 108   |
|                         | Average                               | **46** | **166** | **42** | **116** |

At the time of sowing, the most optimal density was noted for the predecessor sugar beet and soybeans, and equaled 0.92 and 0.94 g/cm³. In the control variant (corn for grain), the density of the topsoil was looser 0.90 g/cm³. At the end of the growing season during harvesting, the optimum soil density was noted after sugar beets 1.10 g/cm³. For the rest of the predecessors, corn for grain, sunflower and soybeans, the soil was uniformly compacted to its equilibrium state and approached the optimal values of 1.03-1.06 g/cm³ for the growth and development of spring barley plants.

The structural and aggregate composition of the soil also plays an important role in the growth and development of spring barley plants. The water, air and thermal regimes of soils, the main physical and mechanical properties of the soil, strongly depend on it. In a soil with a good structure, favorable conditions are created for intensive growth and development of plants [5].

In the studies carried out to study the influence of predecessors on the productivity of spring barley, the structure of the soil differed insignificantly. And the structure of the arable layer of the soil, which was formed by the predecessors, was in direct proportion to the level of its structure (table 2). From sowing to harvesting spring barley, the content of the agronomically valuable fraction by its predecessors increased from 39.2-40.5 % to 47.7-48.8 %, and the silt fraction less than 0.25 mm in size and aggregates more than 10 mm decreased from 59.5-60.8 % to 51.2-52.3 %. The structure
coefficient at the time of sowing for all predecessors ranged from 0.64 to 0.68, and by the time of harvest it increased to the optimal values of 0.91-0.95.

Table 2. The density and structure of the soil in the 0-30 cm layer for the period of sowing and harvesting spring barley, depending on the predecessor (2018-2020)

| Predecessor           | Soil density, g/cm³ | Content of aggregates, % | Structural coefficient |
|-----------------------|---------------------|--------------------------|------------------------|
|                       |                     | 0.25-10, mm (0.25) + (>10) mm |                        |
| For the sowing period |                     |                          |                        |
| Corn for grain (control) | 0.90               | 39.6                     | 60.4                   | 0.66                   |
| Sunflower             | 0.91               | 40.0                     | 60.0                   | 0.67                   |
| Sugar beets           | 0.92               | 39.2                     | 60.8                   | 0.64                   |
| Soy                   | 0.94               | 40.5                     | 59.5                   | 0.68                   |
| Average               | 0.92               | 39.8                     | 60.2                   | 0.67                   |
| For the cleaning period |                  |                          |                        |
| Corn for grain (control) | 1.06               | 48.8                     | 51.2                   | 0.95                   |
| Sunflower             | 1.03               | 48.4                     | 51.6                   | 0.94                   |
| Sugar beets           | 1.10               | 47.7                     | 52.3                   | 0.91                   |
| Soy                   | 1.06               | 47.8                     | 52.2                   | 0.92                   |
| Average               | 1.06               | 48.2                     | 51.8                   | 0.93                   |

Note: the structure and density of the soil are given when applying mineral fertilizers at a dose of N₅₀P₅₀K₅₀

Productivity is an indicator that includes the results of the influence of a large number of factors influencing the productivity of field crops. Predecessors and mineral fertilizers are of great importance among these factors.

Average yield of barley grain for 2018-2020 took the maximum values for the predecessors sugar beets and soybeans when using a high dose of N₅₀P₅₀K₅₀ 5.48 and 5.03 t/ha and an intensive dose of N₅₀P₅₀K₅₀ 5.33 and 5.32 t/ha, respectively. While for corn for grain (control) and sunflower the yield was significantly lower. The lowest yield of barley grain was obtained for the predecessors of corn for grain (control) and sunflower using all studied doses of mineral fertilizers, N₁₀P₁₀K₁₀ 2.50 and 2.62 t/ha, N₃₀P₃₀K₃₀ 3.46 t/ha, N₅₀P₅₀K₅₀ 4.66 t/ha and N₇₀P₇₀K₇₀ 4.73 t/ha (table 3).

According to the results of three-year studies, it has been established that in the Central Black Earth Region, and vegetation conditions of plants, characterized by insufficient precipitation and excess heat during the growth and development of spring barley of the Knyazhich variety, on typical chernozem, medium loamy granulometric composition, with optimal water and agrophysical soil properties, predecessors sugar beets and soybeans provided a significant increase in the yield of barley grain compared to corn for grain (control) and sunflower.

The yield of barley grain on average over the years of research on the predecessors of sugar beets and soybeans was higher than that on the control corn for grain when N₁₀P₁₀K₁₀ was applied at 1.33 and 1.23 t/ha, N₅₀P₅₀K₅₀ 1.41 and 0.95 t/ha, N₅₀P₅₀K₅₀ 0.82 and 0.37 t/ha, and N₇₀P₇₀K₇₀ 0.62 and 0.61 t/ha. When cultivating spring barley according to the predecessor sunflower, the yield was at the level with the control variant.
Table 3. Yield of spring barley, depending on the predecessors and backgrounds of mineral nutrition, t/ha

| Predecessor (factor A) | Doses of mineral fertilizers (factor B) | 2018 | 2019 | 2020 | Average |
|------------------------|----------------------------------------|------|------|------|---------|
| Corn for grain (control) | N_{10}P_{10}K_{10} (control) | 2.30 | 2.10 | 3.09 | 2.50 |
|                        | N_{30}P_{30}K_{30} | 3.43 | 2.79 | 4.16 | 3.46 |
|                        | N_{50}P_{50}K_{50} | 5.33 | 3.42 | 5.22 | 4.66 |
|                        | N_{70}P_{70}K_{70} | 5.04 | 3.63 | 5.47 | 4.71 |
|                        | **Average** | **4.03** | **2.99** | **4.49** | **3.84** |
| Sunflower              | N_{10}P_{10}K_{10} | 1.84 | 2.68 | 3.33 | 2.62 |
|                        | N_{30}P_{30}K_{30} | 3.11 | 3.41 | 4.22 | 3.58 |
|                        | N_{50}P_{50}K_{50} | 4.57 | 4.26 | 4.64 | 4.49 |
|                        | N_{70}P_{70}K_{70} | 4.84 | 4.48 | 4.87 | 4.73 |
|                        | **Average** | **3.59** | **3.71** | **4.27** | **3.86** |
| Sugar beets            | N_{10}P_{10}K_{10} | 3.55 | 2.83 | 5.13 | 3.83 |
|                        | N_{30}P_{30}K_{30} | 4.68 | 4.28 | 5.64 | 4.87 |
|                        | N_{50}P_{50}K_{50} | 5.99 | 4.52 | 5.93 | 5.48 |
|                        | N_{70}P_{70}K_{70} | 5.39 | 4.72 | 5.87 | 5.33 |
|                        | **Average** | **4.90** | **4.09** | **5.64** | **4.88** |
| Soy                    | N_{10}P_{10}K_{10} | 3.83 | 3.01 | 4.36 | 3.73 |
|                        | N_{30}P_{30}K_{30} | 4.53 | 3.99 | 4.70 | 4.41 |
|                        | N_{50}P_{50}K_{50} | 5.53 | 4.47 | 5.09 | 5.03 |
|                        | N_{70}P_{70}K_{70} | 5.66 | 4.90 | 5.39 | 5.32 |
|                        | **Average** | **4.89** | **4.09** | **4.89** | **4.62** |
| Average by predecessors | N_{10}P_{10}K_{10} | 2.88 | 2.66 | 3.98 | 3.17 |
|                        | N_{30}P_{30}K_{30} | 3.94 | 3.62 | 4.68 | 4.08 |
|                        | N_{50}P_{50}K_{50} | 5.36 | 4.17 | 5.22 | 4.92 |
|                        | N_{70}P_{70}K_{70} | 5.23 | 4.43 | 5.40 | 5.02 |
|                        | LSD_{0.05} for predecessors | 0.18 | 0.09 | 0.16 | - |
|                        | LSD_{0.05} for power backgrounds | 0.18 | 0.09 | 0.16 | - |
|                        | LSD_{0.05} for experience | 0.35 | 0.18 | 0.32 | - |

4. Conclusions
In arid conditions on typical chernozem of the Central Chernozem region during the cultivation of spring barley, the reserves of productive moisture at the beginning of the growing season according to predecessors and mineral fertilizers in both the upper soil layer 0-30 cm and 0-100 cm were at a good 44-46 mm and high the level of 160-167 mm, respectively. By the end of the growing season of barley, the reserves of productive moisture in the soil decreased especially intensively in relation to the predecessors of sugar beets and soybeans, the plants of which, due to higher yields, more actively used moisture.

For the period of sowing spring barley, the most optimal soil density was 0.92-0.94 g/cm³ for the predecessors’ sugar beets and soybeans. At the end of the growing season of plants, the soil was uniformly compacted to an equilibrium state and approached the optimal values of 1.03-1.10 g/cm³ for all studied predecessors. The structural and aggregate composition of the soil, which was formed according to the predecessors, contributed to the optimal growth and development of barley plants. The structural coefficient by the time of barley harvesting approached the optimal values of 0.91-0.95. Under the arid growing conditions of the Central Black Earth Region, with the appropriate water and
agrophysical soil properties, when cultivating spring barley of the Knyazhich variety, a high grain yield was obtained for the predecessors of sugar beets and soybeans against the background of the use of mineral fertilizers at a dose of N\textsubscript{50}P\textsubscript{50}K\textsubscript{50} 5.48 and 5.03 t/ha, while after corn for grain and sunflower it decreased to 4.66 and 4.49 t/ha.

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