Agrochemical composition of southern chernozem and humus content under different farming systems in southern Russia

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Abstract. The purpose of the research is to study the content of various nutrients and the amount of humus using different farming systems (the traditional and direct-sowing farming systems) on chernozem in southern Russia. The stationary experiment was conducted in 2015 (five-field crop rotation). In 2021, the first rotation will end. Agrotechnics corresponding for this region was used. Fertilizer rates were applied in equal amounts. The soil is southern chernozem on loesslike light clays. The climate with pronounced continental features is characterized by a significant change in temperatures during various periods of plant vegetation. The average annual air temperature is 10 °C, the annual precipitation is 428 mm. Sampling was carried out in the first decade of October (the first field of crop rotation). The humus content should be one of the objects of environmental monitoring. It determines quantity and quality of crops and their resistance to deshumification. A tendency toward the accumulation of humus was observed when using the direct sowing method. The use of no-till has a positive effect on humus formation, which makes it possible to obtain large yields of better quality. When using the direct sowing method, the main nutrients (phosphorus and potassium) are less accessible. The ratio of carbon to nitrogen decreases which indicates higher nitrogen content.

1. Introduction
Agriculture is one of the most important sectors of the economy. The production of agricultural products is one of the main indicators of the national wealth. Agriculture and related industries make up the national agro-industrial complex [1–3]. The south of Russia has fertile lands, a sufficient amount of solar energy, but due to the arid climate, agricultural producers face great difficulties in dry years. Despite the scientific and technological process, the dependence on weather and climatic conditions is larger than in other sectors of the economy [4, 5].

Therefore, the main direction is conservation and rational use of available moisture [6–8].

Due to the presence of plant debris on the surface that reflects solar radiation back into space, the direct sowing system or no-till allows plants to economically use soil moisture. In dry years, yield and product quality are higher than for the traditional farming system [9–11].

Nitrogen, phosphorus, and potassium are macroelements whose content should be sufficient for the normal development of agricultural plants [12–14]. Humus is organic, dark-colored part of the soil formed as a result of the biochemical conversion of plant and animal residues. It contains humic acids (most important for soil fertility) and fulvic acids (trenic acids). Humus contains basic elements of plant nutrition, which, under the influence of microorganisms, become available to plants. Humic
substances are produced as a result of complex biochemical and chemical processes. Organic matter entering the soil is the main material for life processes of microflora. Entering complex interactions with the mineral part of soil, humic substances form various cements, fastening dispersed soil particles into aggregate lumps forming structural aggregates. In the structural soil, the hydrothermal and air regime improves and favorable conditions are created for the development of the root system of higher plants, the vital activity of microorganisms and the mesofauna. The more humus in the soil, the more fertile it is. With the proper use of soil, its amount does not decrease; with the improper use, it can decrease. The soil is especially depleted if organic fertilizers are not applied (manure, bird droppings, plant debris) [15–17].

The purpose of the research is to study the content of various nutrients and the amount of humus when using different farming systems (the traditional system and the direct-sowing farming system) on southern chernozem in southern Russia.

2. Research methods and conditions

The stationary experiment was conducted in 2015 in the Central steppe of Crimea (five-field crop rotation). In 2021, the first rotation will end. Agrotechnics corresponding for this region was used. Fertilizers were applied in equal amounts. Sampling was carried out in the first decade of October (the first field of crop rotation).

The soil is southern chernozem on loesslike light clays. The humus content in the arable layer was 2.35 %, mobile phosphate was 4.4 mg/100 g of soil, exchange potassium was 39.1 mg/100 g of soil, and the weighted average pH was 7.6. The thickness of the humus horizon was 50–70 cm. The color was dark gray. The structure was lumpy. The structure was loose from the bottom, compacted. The particle size distribution was light clay [18]. The climate with pronounced continental features was characterized by a significant change in temperatures during various periods of plant vegetation. The average annual air temperature was 10 °C, the annual precipitation was 428 mm [19].

The weather conditions prevailing in 2016 that preceded the sampling are presented in Table 1.

Table 1. Weather conditions preceding the soil sampling for the content of nitrogen, phosphorus, potassium and humus when using different farming methods, 2016

| Month  | Decade | Air temperature | Soil temperature | Precipitation |
|--------|--------|-----------------|------------------|--------------|
|        |        | average         | maximum          | 0-5          | 0-10 | 0-20 |                 |
| August | I      | 26.7            | 36.5             | 29.1         | 28.8 | 27.6 | 9.50            |
|        | II     | 24.0            | 36.9             | 27.3         | 27.1 | 26.3 | 8.30            |
|        | III    | 25.0            | 34.2             | 26.9         | 26.8 | 26.0 | 4.70            |
|        |        | 21.0            | 32.2             | 24.5         | 24.3 | 23.8 | 0.00            |
| September | II   | 18.7            | 30.5             | 22.3         | 21.6 | 21.7 | 84.4            |
|        | III    | 13.2            | 21.4             | 16.5         | 15.5 | 16.1 | 0.70            |
| October | I      | 14.5            | 25.2             | 16.7         | 16.3 | 16.6 | 2.80            |

The weather conditions in 2017 that preceded the sampling are presented in Table 2.

Table 2. Weather conditions preceding soil sampling for the content of nitrogen, phosphorus, potassium and humus when using different farming methods, 2017

| Month  | Decade | Air temperature | Soil temperature | Precipitation |
|--------|--------|-----------------|------------------|--------------|
|        |        | average         | maximum          | 0-5          | 0-10 | 0-20 |                 |
| August | I      | 26.7            | 36.5             | 30.7         | 29.7 | 28.0 | 0.00            |
|        | II     | 25.9            | 37.2             | 26.7         | 26.5 | 26.1 | 53.1            |
|        | III    | 20.7            | 32.9             | 24.3         | 24.3 | 24.0 | 0.10            |
|        |        | 20.9            | 33.8             | 23.5         | 23.3 | 22.6 | 0.00            |
| September | II   | 23.7            | 38.8             | 25.1         | 24.8 | 23.9 | 0.00            |
|        | III    | 16.9            | 36.3             | 19.7         | 20.1 | 20.7 | 0.10            |
| October | I      | 12.6            | 28.6             | 14.5         | 15.1 | 16.0 | 10.1            |
The weather conditions in 2018 that preceded the sampling are presented in Table 2.

**Table 3.** Weather conditions preceding soil sampling for the content of nitrogen, phosphorus, potassium and humus when using different farming methods, 2018

| Month | Decade | Air temperature average (°C) | Soil temperature 0-5 (°C) | Soil temperature 0-10 (°C) | Soil temperature 0-20 (°C) | Precipitation (mm) |
|-------|--------|-----------------------------|---------------------------|----------------------------|----------------------------|------------------|
| August | I      | 25.6                        | 27.5                      | 27.1                       | 26.1                       | 4.30             |
|        | II     | 24.8                        | 26.9                      | 26.5                       | 25.8                       | 0.00             |
|        | III    | 24.8                        | 26.5                      | 26.2                       | 25.5                       | 0.00             |
| September | II  | 18.9                        | 20.3                      | 20.6                       | 20.9                       | 58.7             |
|        | III    | 14.9                        | 17.0                      | 17.4                       | 18.2                       | 4.70             |
| October | I      | 13.6                        | 14.9                      | 15.3                       | 16.1                       | 7.10             |

Weather conditions in 2019 that preceded the sampling are presented in Table 4.

**Table 4.** Weather conditions preceding soil sampling for the content of nitrogen, phosphorus, potassium and humus when using different farming methods, 2019

| Month | Decade | Air temperature average (°C) | Soil temperature 0-5 (°C) | Soil temperature 0-10 (°C) | Soil temperature 0-20 (°C) | Precipitation (mm) |
|-------|--------|-----------------------------|---------------------------|----------------------------|----------------------------|------------------|
| August | I      | 22.6                        | 24.8                      | 24.6                       | 23.9                       | 5.30             |
|        | II     | 23.2                        | 24.9                      | 24.9                       | 24.3                       | 2.30             |
|        | III    | 25.3                        | 26.5                      | 26.2                       | 25.3                       | 0.00             |
| September | II  | 18.6                        | 20.2                      | 20.7                       | 20.9                       | 17.2             |
|        | III    | 14.7                        | 16.3                      | 16.6                       | 16.9                       | 2.20             |
| October | I      | 13.7                        | 15.3                      | 16.0                       | 16.6                       | 4.10             |

The weather conditions are presented for each research year, since the results of chemical analyses may vary depending on the prevailing conditions.

Nitrogen content was determined according to Kjeldahl’s method, phosphorus and potassium content – according to Machigin’s method, humus content – according to Tyurin’s method [20].

### 3. Research results

It is known that humus determines favorable nutritional, water-air thermal and biological regimes, as well as soil structure. In such soils, the risk of contamination with toxic substances is reduced (since fulvic acids bind heavy metal ions to insoluble compounds, namely salts). When carbon-rich mass is added to the soil (cattle manure, bird droppings, crop residues, green manure), the ratios of carbon and nitrogen change. Ammonia nitrogen turns into nitrate, losing an electron \((\text{NH}_3 \rightarrow \text{NO}_3)\), which explains the presence of energy in humus. Nitrate nitrogen is available to agricultural plants, yet humus is a direct source of nitrogen.

When using the traditional sowing method, 30 tons/ha of cattle manure, as well as mineral fertilizers for primary processing and sowing were added. In the direct sowing system, only mineral fertilizers were applied during sowing. For winter wheat and winter barley, phosphorus was introduced for the next crop rotation in the amount of 100 kg/ha. Since there is much more productive moisture in the fall, and when sowing spring crops, seedlings of cultivated plants can be inhibited if the main fertilizer rate is applied to the sowing line. Therefore, for spring crops, phosphorus is introduced only in the starting dose \((P_{10})\). When sowing peas, an inoculant of nitrogen-fixing bacteria was used.

Table 5 presents the yield of winter barley over the research years. In 2019, the latest samples were taken on the field of winter barley to determine the content of nutrients and humus, which will be further compared with the initial state of southern chernozem. The yield was significantly higher in...
2017 and 2018 when the traditional system was used. In 2019, the direct sowing method was used. In 2016, there was no significant difference between the options. Accordingly, with a higher yield, the nutrient removal increases. When calculating the content of the nutrients, this difference was taken into account for all the crops.

### Table 5. Productivity of winter barley when using different farming methods, t/ha, 2016–2019

| Farming system | 2016 | 2017 | 2018 | 2019 |
|----------------|------|------|------|------|
| Traditional    | 3.64 | 3.96 | 3.90 | 4.50 |
| Direct sowing  | 3.59 | 3.06 | 3.20 | 5.37 |
| LSD05          | 0.15 | 0.75 | 0.54 | 0.67 |

The change in the humus content in the traditional farming system and the ratio of carbon to nitrogen are presented in Table 6. In the soil layer 0–10 cm, the results are in the range of an experimental error. If you take a horizon of 10–20 cm, there is an increase in the humus content, but the increase is not mathematically proven. In the soil layer of 20–30 cm, the difference between 2019 and 2016 is 0.44%, with LSD05 – 0.65%, the increase is in the range of an experimental error. The ratio of carbon to nitrogen was 11.86, 14.72, and 13.25 (0–10, 10–20, 20–30, respectively).

### Table 6. Changes in the humus content when using the traditional farming method, %, 2016–2019

| Soil horizon, cm | Research years  | LSD05 | Carbon to nitrogen ratio |
|------------------|-----------------|-------|-------------------------|
|                  | 2016           | 2017  | 2018                   |
| 0–10             | 2.30           | 3.10  | 3.06                   |
| 10–20            | 2.30           | 2.70  | 2.73                   |
| 20–30            | 2.21           | 2.00  | 1.98                   |

The change in the humus content in the direct sowing system and the carbon to nitrogen ratio are presented in Table 7. In the 0–10 cm layer, the results are in the range of experimental an error. In the 10–20 cm layer, an increase is not significant. In a layer of 20–30 cm, the results are in the range of an experimental error. There is a tendency towards an increase in the humus content over the years. The ratio of carbon to nitrogen in the direct sowing system was 10.66, 11.56, and 10.75 (0–10, 10–20, 20–30, respectively).

### Table 7. Changes in the humus content when using the direct sowing method, %, 2016–2019

| Soil horizon, cm | Research years  | LSD05 | Carbon to nitrogen ratio |
|------------------|-----------------|-------|-------------------------|
|                  | 2016           | 2017  | 2018                   |
| 0–10             | 2.13           | 2.60  | 2.47                   |
| 10–20            | 2.00           | 2.20  | 2.28                   |
| 20–30            | 1.95           | 2.40  | 2.13                   |

Using the direct sowing method, the ratio of carbon to nitrogen decreases. C: N – the degree of enrichment of humus with nitrogen is one of the most important indicators characterizing the humus state of the soil and enrichment with nitrogen (levels C: N <5 very high; 5–8 high; 8–11 medium; 11–14 low;> very low). In the traditional system, the nitrogen content is low in the layers of 0–10 and 20–30 cm; in the layer of 10–20 cm, it is very low. For direct sowing, in the layers of 0–10 and 20–30 cm, it is average; in the layer of 10–20 cm, it is low.

It was established that even when plants are fully provided with mineral nitrogen, yields are formed to a large extent by 40–50 % due to their own soil nitrogen (from humic substances). Therefore, the intensive use of mineral fertilizers without organic substances creates to a negative balance of nitrogen and humus, NH₃ (ammonia) accumulates because the amount of carbon-containing compounds is insufficient.
Another factor affecting the humus state is agrotechnical methods of tillage. In our experiments, we used traditional sowing and direct methods for 4 years, humus horizons were assimilated differently. In traditional crops, under the same conditions, nitrogen was less assimilated, which is confirmed by the C: N ratio, which is in the range of 11–14, which indicates a low degree of nitrogen supply (Table 8).

Table 8. The total nitrogen content when using the traditional farming method, 2019

| Soil horizon, cm | Parameters | C% | C:N | %∑ N (% of total nitrogen) | T |
|------------------|-----------|----|-----|--------------------------|---|
| 0–10             |           | 1.79 | 12.3 | 0.145                   |   |
| 10–20            |           | 1.45 | 13.3 | 0.109                   |   |
| 20–30            |           | 1.39 | 12.2 | 0.114                   |   |

In plots with a direct sowing method, this ratio decreases, which characterizes soils with an average level of nitrogen (Table 9).

Table 9. Total nitrogen content when using the direct sowing method, 2019

| Soil horizon, cm | Parameters | C% | C:N | %∑ N (% of total nitrogen) | T |
|------------------|-----------|----|-----|--------------------------|---|
| 0–10             |           | 1.56 | 10.6 | 0.147                   |   |
| 10–20            |           | 1.56 | 11.1 | 0.141                   |   |
| 20–30            |           | 1.50 | 11.0 | 0.135                   |   |

In the direct sowing system, where there are no tillages, nitrogen was assimilated to a greater extent compared to the traditional system. Therefore, the humification process will be more intensive.

One of the factors of nitrogen assimilation is the presence of plant residues. One of the negative factors affecting the slowdown of humification in the Central steppe of Crimea is weather conditions: high air temperature and a low soil moisture content [9]. Such conditions contribute to the rapid mineralization of plant residues and the delayed formation of humus.

The phosphorus and potassium content for different farming systems are presented in Table 10. As you can see, in the direct sowing system, in 2019, phosphorus content was 1 mg/100 g of soil which is less than in the traditional system. Potassium content was less by 4 mg/100 g of soil. On average, over the years of research, phosphorus content was less by 1.57 mg/100 g of soil, and the amount of potassium was the same.

Table 10. The phosphorus and potassium content in different farming systems, mg/100 g of soil, 2016–2019

| Research years | Traditional system | Direct sowing system |
|----------------|--------------------|----------------------|
|                | P$_2$O$_5$ | K$_2$O | P$_2$O$_5$ | K$_2$O |
| 2016           | 4.90     | 31.0   | 3.50     | 36.9   |
| 2017           | 5.00     | 34.8   | 4.50     | 38.0   |
| 2018           | 7.80     | 35.7   | 4.40     | 30.4   |
| 2019           | 6.40     | 36.0   | 5.40     | 32.0   |
| average        | 6.02     | 34.4   | 4.45     | 34.3   |
| LSD$_{05}$     | 0.54     | 3.21   | 0.45     | 3.65   |

4. Conclusion

The humus content in soils should be one of the objects of environmental monitoring, which determines the quantity and quality of the crops and the resistance to dehumification. In our studies, a tendency toward the accumulation of humus when using the direct sowing method was observed. The use of no-till has a positive effect on humus development, which makes it possible to obtain large yield and improve its quality. When using the direct sowing method, the main nutrients (phosphorus
and potassium) are less accessible. The ratio of carbon to nitrogen decreases when using the direct
sowing method, which indicates a higher nitrogen content in comparison with the traditional system.
Our research will be continued. After the second rotation, it will be determined how much nitrogen,
phosphorus, potassium and humus will change when using various farming methods in the south of
Russia.

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