The effect of zero-tillage technologies on the transformation of organic matter in leached chernozem

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Abstract. The article considers the influence of resource-saving technologies in agricultural production during tillage. The possibilities of zero tillage in the conditions of agriculture ecologization are determined. The necessity of using soil protection technologies in connection with the use of tank mixture in the processing of the reference area is justified. The quantitative content of total organic carbon ($S_{org}$), as well as alkaline-soluble and water-soluble organic matter, was estimated. Their share in the structure of $S_{org}$ is determined. For the first time in the agricultural zone of the Krasnoyarsk Region, the long-term effect (9-10 years) of zero technology on the dynamics of organic carbon content and its mobile forms was determined. Chemical and physico-chemical indicators relative to seasonality are presented. The degree of mobility of the organic matter of the soil treated by zero technology is determined and the reasons for this fact are revealed. It is shown that the zero technology reduces the degree of mobility of organic matter.

1. Introduction
In the modern conditions of the "green economy" development, much attention is paid to the preservation of soil fertility. Resource conservation is becoming a key task of agricultural activity [1-5]. In the Russian Federation, having significant land resources, it occupies the 4th place in the world in terms of land cultivation and use in agriculture. A set of measures aimed at digitalizing agriculture in the regions will help regional authorities to identify the potential of rural areas and develop effective models of agriculture [6-11]. In the regions of the Russian Federation, innovative technologies are being developed and actively applied to improve the efficiency and quality of agricultural production. One of the most promising areas for the use of land resources is the use of zero-tillage technologies [12-16].

In recent years, the minimization of tillage is considered as one of the most important conditions for the agriculture ecology. Carbon is an element that binds together the main components of the agrocenosis in the soil-plant-surface layer of the atmosphere during the biological cycle [17-20]. The impact of reduced tillage on the organic carbon content is unclear. Research results on this issue often contradict each other. In many studies, the content of soil organic carbon under zero treatment differs significantly from its content under normal and reduced treatment. However, the content of soil organic carbon in conventional and reduced treatment does not differ significantly. The mechanisms governing the balance between increased or no carbon conservation after the transition to zero tillage are not yet clear. The practical problem of research is the reduction of the share of labile organic carbon in agricultural soils, due to the permanent use of traditional dump processing methods.
The purpose of the paper is to evaluate the parameters for the organic carbon content of different availability degrees in the soil under conditions of zero processing technology.

Research questions:

- To evaluate the intra-seasonal dynamics of the studied organic compounds of leached chernozem;
- Determine the content of organic carbon, alkaline-soluble and water-soluble organic compounds in the studied soil layers.

2. Materials and methods

The research was carried out on the production experiment “Shilinskoye” in the Krasnoyarsk forest-steppe, located within the Chulym-Yenisei denudation plateau of the southwestern suburb of Central Siberia (56037’ n. l. and 93012’ e. l.). The experiment was founded in 2006. During the growing season of 2013, the land mass, where the zero-treatment technology was used, was in the conditions of chemical steam. Here, a three-time treatment was carried out with a tank mixture of the herbicides "Topic" and "Cowboy", the fungicide "Alto Super" and the insecticide "Karate". In the third decade of August, winter triticale was sown with a combined SS-6 unit without preliminary soil preparation with mechanical seeding. Its growing season was in 2014.

The action period of soil protection technologies at the beginning of our observations was nine years. Within the production crops, a reference plot with an area of 500 m$^2$ of elongated shape was allocated. Three times during the growing season, soil samples were taken from layers 0-5 and 5-20 cm by the snake method. The sample size (n = 15) was calculated based on the amount of variation in soil fertility determined before the experiment.

In the years of observations, the distribution of heat and moisture was characterized by the following parameters (table 1).

| Table 1. Meteorological indicators in the observations years. |
|---------------------------------------------------------------|
| **Year** | **Month** | **Mean air temperature, °C** | **Precipitation, mm** | **Sum over the growing season** |
| --- | --- | --- | --- | --- |
| | May | June | July | August | September | |
| 2014 | 6.8 | 16.0 | 19.2 | 15.9 | 6.5 | 1565 |
| 2015 | 10.9 | 17.0 | 19.9 | 16.5 | 8.4 | 1535 |
| Norm(1980-2010 yr.) | 8.7 | 15.5 | 18.3 | 14.9 | 8.3 | 1627 |
| 2014 | 53.5 | 50.4 | 89.4 | 74.9 | 32.4 | 300.6 |
| 2015 | 30.9 | 32.6 | 68.5 | 62.9 | 73.4 | 268.3 |
| Norm(1980-2010 yr.) | 34.7 | 46.8 | 64.5 | 58.6 | 42.5 | 247.0 |

During most of the months from the warm period in 2014, the humidity was slightly increased relative to the average long-term norm. The maximum amount of precipitation fell only in July - 89 mm. This combination of heat and moisture provides sufficient moisture during the growing season of field crops. According to G. T. Selyaninov, the value of the hydrothermal coefficient (HTC) for June-August was 1.3. The beginning of the growing season in 2015 was characterized by higher temperatures in comparison with the previous season and further to the autumn; the average monthly values exceeded the parameters of 2014. The amount of precipitation, on the contrary, was significantly lower than last year. The value of the SCC for the period of active vegetation was 1.0. Thus, the conditions of the growing season of 2015 were estimated as more arid, in comparison with the season of 2014.

Chemical and physico-chemical parameters were obtained from GOST 26213-91 Soil. Methods for determining organic matter [21]. The average laboratory soil sample was evenly distributed on paper
with a layer about 5 mm thick. From each square to the entire depth of the layer, a small amount of soil was taken with a spatula and placed in a bag of tracing paper. The mass of the soil sample was 3 g. The roots and other organic residues were not removed from the analytical soil sample. Next, the soil was sifted through a sieve, first with holes of 1 mm, then - 0.25 mm. The organic matter that is soluble in an alkaline medium is not homogeneous, has a difficult to recognize structure, and is a conglomerate of individual compounds, broken condensed formations, and organo-mineral complexes. In the prepared samples, the content of organic ($S_{org}$) and alkaline-soluble carbon ($C_{0.1NaOH}$) according to I. V. Tyurin was determined in the ratio of 1:5 and 0.1n NaOH in the ratio "sample: extractant" = 1:20. At the same time, soil samples were taken for moisture using a drill in layers. Humidity was determined by the thermostatic-weight method. The selection period of soil samples is timed to the main phases of the agricultural crops development.

3. Results

Consider how the organic carbon of the soil was distributed in the variants of the experiment in dynamics (figure 1).

![Figure 1](image.png)

**Figure 1.** Dynamics of the $S_{org}$ content in the conditions of zero technology.

Dynamic changes of $S_{org}$ in the 2014 season were expressed reliably with a maximum in mid-summer. It is known that plant residues are the main source of organic carbon in the soil. Therefore, leaving more plant residues on the surface at zero technology contributes to an increase in the concentration of organic carbon in the soil. The rate of decomposition of plant residues, and hence the dynamics of transformations, depends not only on the volume of plant residues left, but also on the characteristics of the soil and the composition of plant residues.

The weather conditions in 2015 were very different from the previous season. The first half of summer was characterized by significantly less precipitation, and the thermal regime of the entire season was almost higher than the norm in terms of the amount of heat (see table 1). Nevertheless, the significance of the intra-seasonal dynamics of organic carbon was generally similar to the growing season of 2014.

Consider how the nine-decade periods of using soil protection technologies affected the differentiation of the compared soil layers by the content of organic carbon in them (table 2).

**Table 2.** The significance of differences in the content of $S_{org}$ in the compared layers $t_{0.5} = 2.14$.

| Option                      | Dates | June | July | September |
|-----------------------------|-------|------|------|-----------|
| Zero processing             | 2014  | 0.7  | 2462 | -2.5      |
|                            |       |      | 2396 | 3380      |
|                            |       |      | -2.5 | 3785      |
|                            |       |      |      | 1.4       |
|                            |       |      |      | 2641      |
|                            |       |      |      | 2470      |
Significant changes in the content of \( S_{\text{org}} \) were noted only in July. The increase in the concentration of organic carbon in the soil in mid-summer was facilitated by an increase in the biomass of plant residues on the soil surface with this method of tillage. At the same time, no significant differences were found in early summer and autumn. An interesting pattern was discovered in two years of observations. In mid-summer (in July), significant differences between the layers were found, and with maxima in the layer of 5-20 cm. This fact probably indicates a significant influence of the root plants systems in the accumulation of organic carbon matter during the period of their greatest production. Given the absence of mechanical loosening, warm weather, and root exudate maxima, it becomes obvious that \( S_{\text{org}} \) with zero technology is actively formed not only in the surface layer.

Mobile organic matter consists of a variety of organic compounds that are products of biochemical processes occurring in the soil. The use of zero technology, apparently, caused processes that inhibit the decomposition of plant residues to a state of solubility by decinormal extraction. The nature of the dynamics of \( C_{0.1\text{NaOH}} \) under the conditions of using zero technology in 2015 was much more pronounced in comparison with the previous growing season (table 3). One of the factors that could cause this, in our opinion, was an increased level of humidity fluctuation and, as a result, a rhythm changing in the receipt of root secretions.

![Figure 2. Dynamics of the \( C_{0.1\text{NaOH}} \) content in the conditions of zero technology.](image)

| Option                  | Dates | June | July | September |
|-------------------------|-------|------|------|-----------|
| Zero processing         | 2014  | 8.9  | 7.1  | 5.8       | 349       |
|                         |       | 322  | 366  |           | 325       |
|                         |       | 266  | 325  |           | 294       |
|                         | 2015  | 2.5  | 1.0  | 4.1       | 191       |
|                         |       | 425  | 202  |           | 401       |
|                         |       | 280  | 401  |           | 142       |

As the results showed, significant differences were observed in the compared layers of 0-5 and 5-20 cm in June of the 2014 growing season. Here, in the surface layer, the content of alkaline-soluble carbon significantly dominated the soil of the underlying layer. Probably, the plant remains left over from the previous season, in June, passed the stage of humification more actively. In the middle of summer, the
The opposite situation was observed. This indicates the differences in the conditions that are formed in the analyzed layers in dynamics. In 2015, the content of alkaline-soluble carbon in the 0-5 cm layer significantly dominated the soil of the underlying layer at the beginning and end of the growing season. The differences in the excess of the alkaline-soluble carbon content in the surface layer compared to 5-20 cm are probably due to the preservation of plant residues on the soil surface from the previous season.

One of the most significant indicators for assessing the mobility level of soil organic matter is the proportion of C_{0.1NaOH} from the total content of S_{org} (\%).

Table 4. Percentage of mobile organic matter (C_{0.1NaOH} / S_{org}, %).

| Option          | Dates       | June  | July  | September |
|-----------------|-------------|-------|-------|-----------|
| Zero processing | 2014        | 6     | 0.5   | 5.5       |
|                 | 2015        | 12    | 12    | 5         |

The degree of mobile organic matter for the soil treated according to the zero technology is estimated as low (Table 4). In our opinion, the probable reasons for this fact could be a reduced degree of soil mineralization for this variant, as well as a decrease in humification activity. In general, the use of zero technology caused a minimal level of mobility. Summarizing the information about the degree of mobile organic compounds, it should be generally said that it was not at a high level. For forest-steppe soils of the Krasnoyarsk region, the characteristic proportion of C_{0.1NaOH} / S_{org} varies in the range of 20-25 %. Therefore, it can be argued that soil protection technologies can cause a decrease in the degree of mobile organic substances evaluated through the alkaline-soluble fraction. Determining the results for the application of soil protection technologies [22-26] in soil cultivation helps us to develop a strategy for the use of land resources in the region [27-33].

4. Conclusion

Dynamic changes in S_{org} when using zero technology were expressed reliably with a maximum in midsummer. During this period, significant differences were found between the studied soil layers in the content of S_{org}, and with maxima in the layer of 5-20 cm.

The use of zero technology significantly reduced the concentration of C_{0.1NaOH} and the degree of its mobility, on the other hand, contributed to the stabilization of the content of C_{0.1NaOH} during the field season. The degree of mobile organic matter of the soil treated by the zero technology is estimated as low.

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