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The effect of short-term crop rotation with different proportions of sunflower on cellulolytic activity of the soil

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Abstract

The article presents the results of the 2020–2021 research carried out in the experimental field of Kharkiv National Agrarian University named after V. V. Dokuchaev, located in the area of the Left Bank Forest-Steppe of Ukraine. We aimed to find out whether the cellulosolytic activity of the soil depends on the increase in the proportion of sunflower in short-term crop rotations. The climate of the region is moderately continental with insufficient and unstable level of hydration. The influence of short-term crop rotations with different sunflower saturation on the degree of cellulosolithic activity of the arable soil layer were studied. The study of the general cellulosolytic activity of the soil was carried out by the method that is based on the intensity of cellulose decomposition. Probably activity of cellulosolithic microorganisms depends not only on the weather and climatic conditions and certain agrophysical indicators of soil fertility, but also on the amount of plant remains left by the sunflower. The higher the percentage of saturation of crop rotation with sunflower is the higher is the intensity of the decomposition of the canvas. On average, over the years of research, the highest intensity of development of cellulose-destroying microorganisms (28.6%) in the arable soil layer (0–30 cm) was in the field of five-field crop rotation, where the share of sunflower was 60%. Although clean fallow contributes to the accumulation of moisture in the soil, practically the absence of plants does not ensure its cellulosolithic activity. Research showed that fallow and sunflower have different effects on soil moisture. The crop rotation field with 20% sunflower saturation in the 0-30 cm layer of soil contained the maximum – 15.6% of moisture.

1. Introduction

Soil microorganisms play a key role in preserving and restoring soil fertility. This is due to the mineralization of organic material into available plant nutrients. Therefore, it is important to maintain a high microbiological activity in the soil (Volkohon, 2005; Yan et al., 2015). The direction and pace of transformation of organic material entering the soil are limited by the activity of soil microorganisms (Manzoni and Porporato, 2009). It is precisely with this part of the soil biota where transformations of organic compounds take place. (Shykula and Demydenko, 2000; Bastida et al., 2006; Stuart Chapin et al., 2009). Plant remains play an important role in improving the morphological and genetic properties of chernozem. Their amount is directly related to the action of abiotic factors of the soil environment: temperature, moisture, nutrient availability (Demydenko, 2005). The period of biological activity of the soil can be extended due to the optimal agrophysical condition, presence of a layer of mulch on the soil surface and ideal perfect structure of the arable soil layer (0–30 cm). At the same time, the soil moisture should not be lower than the wilting moisture (Demydenko, 2013). This is especially important for the driest period of the year in Ukraine (July–August).

Cellulolytic activity is an indicator of soil biological activity (Iutynska, 2006; Varbanets and Borzova, 2010; Veum et al., 2014). There are representatives of the genera *Pseudomonas, Cytophaga, Sporocytophaga, Cellvibrio, Vibrio, Polyangium, Sporangium,* as well as bacteria of *Actinomycetaceae* species and micromycetes among cellulose-destroying microorganisms (Hatami et al., 2008; Vostrykova, 2012). Decomposing cellulose, they secrete into the environment some enzymes that contribute to creation of humic substances and the formation of structural aggregates. The more intense this process is, the faster the cycle of elements occurs and the better the plant are provided with nutrients (Kurdysh, 2009; Gupta et al., 2012; Hepenko, 2013; Kovalov et al., 2015). Both anthropogenic and natural origin various factors influence soil microbial activity. (Lyko et al., 2017). Climate influence microbial communities by determining both temperature and humidity, which influence microbial communities and activities (Prescott et al., 2004;

Hackl et al., 2005; Fenoy et al., 2016). The available soil moisture is important for the development of microorganisms.

The study of the cellulolytic activity of the soil makes it possible to understanding deeper and reveal regularities in the processes of organic matter transformation. At this anthropogenic impact on the soil and its properties are taken into account (Symochko, 2008). Crop rotation, precursors and technologies of growing crops including sunflower have a significant influence on cellulolytic activity. As the intensity of microorganisms increases, the productivity of crops increases too, organic matter accumulates in the soil, and its physical and chemical properties and fertility improve as well (Zinchenko, 2001; Boiko et al., 2005; Iutynska, 2006).

Organic remains of plant origin are transformed in the soil under the influence of microorganisms. This ultimately leads to its humification and complete mineralization, with the formation of intermediate products that can have a physiological effect on the next crop of rotation (Iutynska, 2006). Although soil microorganisms play a central role in the soil processes we are only beginning to understand how microbial communities are shaped by environmental factors (Brockett et al., 2012).

To date, the problem of the interrelationship between crops and soil microorganisms has been insufficiently studied. It becomes especially relevant due to changes in weather and climatic conditions and needs to be solved by crop rotation factors. The purpose of this study is to determine the effect on the cellulolytic activity of the soil of short-term crop rotations with different percentages of sunflower.

2. Materials and methods

Studies to determine the cellulolytic activity of the soil in sunflower crops were performed based on the chair of Farming named after O. M. Mozheiko of the experimental field of Kharkiv National Agrarian University named after V. V. Dokuchaev. Determining the intensity of decomposition of the canvas objectively reflects the state and activity of the microbiota in specific soil and climatic conditions. The place of research is located in the eastern part of the Kharkiv region of Ukraine. The complexity of the climatic conditions of the Kharkiv region of Ukraine for agriculture is also revealed in not existing guaranteed annual sufficient moisture apart from it in certain years warm resources are much lower than are needed for crops. According to the meteorological station of KhNAU, during the growing season of sunflower (May–September) the average long-term precipitation is 278 mm, air temperature + 17.7°C. The peculiarity of the conditions for 2020–2021 research in the period of exposure of the canvas was insufficient moisture. During the vegetation period of sunflower in 2020, precipitation was 114 mm less than normal, and the average air temperature was 19.8°C, which is 2.1°C above the climatic norm. Atmospheric precipitation of the vegetation period of sunflower in 2021 had a torrential character in June – 81.9 mm, which is 22.9 mm higher than the average long-term norm. In July and August, precipitation was lower by long-term averages of 51.5 and 44.2 mm, respectively. Precipitation in 2021 was 197.7 mm, which is 81.3 mm less than the long-term norm, and the excess of the average daily air temperature by 2.5°C compared to the perennial. Therefore, the vegetation of sunflowers in this period took place in relatively unfavorable conditions.

The soil cover of the experimental field is represented by typical chernozem heavy loam on loess-like loam (Chernozem Haplic). This soil is characterized by good physical and mechanical, agrochemical, and some chemical properties, fairly high reserves of nutrients available to plants, high humus content, and intensive biological activity. The arable layer of the soil (0–30 cm) contains humus (according to Tyurin) – 4.9–5.1%, easily hydrolyzable nitrogen (according to Kornfield) – 81 mg/kg of soil, mobile forms of phosphorus and potassium (according to Chirikov) – 100 and 200 mg/kg of soil. Content of exchangeable cations: calcium – 37.8%, magnesium – 6.6%, sodium – 0.49%, potassium – 0.5%, hydrogen – 21 mg-equiv./kg soil. The soil reaction − pH: aqueous – 7.0, salt – 5.2–5.6. Groundwater lies at a depth of about 18 m (Tykhonenko and Dehtiarov, 2016). Chernozem soils are characterized by a fairly high cellulolytic activity (70–80%) (Ellanska et al, 2008).

Variants of short-term (5-field) crop rotations with different proportions of sunflower in the structure of the sown areas were studied (Table 1). Control variant − fallow.

Sunflower hybrid – Cruiser LG59580. The size of the sowing area is 750 m^2, the accounting area is 100 m^2. The technology of sunflower cultivation is generally accepted for the conditions of the Forest-Steppe zone of Ukraine. After harvesting the precursor, disking is carried out to a depth of 6–8 cm and plowing to a depth of 25–27 cm. In the spring, harrowing with heavy harrows, pre-sowing cultivation to a depth of 6–8 cm. For the main fertilization, nitrophosk is used at the rate of 400 kg/ha. Sunflower is sown at a soil temperature of 8–10°C. The rate of sowing is 50–55 thousand seeds per hectare. The depth of seed wrapping is 6–8 cm. The width of the rows is 70 cm. Protection of crops from weeds is carried out by cultivation and application of the herbicide Harness (2 l/ha). Harvesting was carried out by direct combining at a seed moisture content of 10–12% (Tishchenko et al., 2015).

Table 1
Crop rotation structure (in %)

Crop rotation structure				
Pea	Winter wheat	Corn	Winter rye	Sunflower
20	20	20	20	**20**
20	20	–	20	**40**
–	20	–	20	**60**

Studies were performed by a method based on the intensity of cellulosolytic decomposition. This gives a fairly accurate idea of the effect of sunflower cultivation in short-term crop rotations on the intensity of decomposition of plant residues in the soil (Béguin and Aubert, 1994; Lynd et al., 2002). To determine the intensity of cellulose decomposition, a flax tissue measuring 10 cm was attached to the polymer film. The film was sterilized with alcohol and the tissue in an autoclave. A cut is made in the soil and a canvas is attached to its vertical wall. On the other hand, polyethylene is pressed by the soil. The canvas was laid every 10 cm to a depth of 30 cm. Fabric applications are left in the soil for 45 days. The experiment was repeated three times. After 45 days, the cloth is taken out, washed from the soil, dried, and weighed. The fact of decomposition of the canvas was determined by the loss of its initial mass. The formula was used to determine cellulolytic activity based on mass loss (in percent):

$$\frac{m_1 - m_2}{m_1} \times 100 \qquad \text{Equation 1}$$

where: m_1 − the starting mass, m_2 − the mass of the remaining fabric. To assess the cellulolytic activity of the soil used the scale: 10% – very weak, 10–30 – weak, 30–50 – medium, 50–80 – strong, and over 80% – very strong.

Soil moisture was determined by the thermostatic weight method (Soil survey standard test method, 1994). The method is based on removing soil moisture by oven-drying a soil sample until the weight remains constant. The moisture content (%) is calculated from the sample weight before and after drying. The aluminum containers are weighed beforehand. Containers with soil samples are closed with a lid and weighed again with an accuracy of 0.1 g. Next, the open boxes together with the lid are placed in a drying cabinet and the soil is dried to a constant weight (at a temperature of 105°C). After drying, the containers are removed from the drying cabinet and weighed again, obtaining the value of the weight of completely dry soil.

The formula for calculating moisture:

$$\text{MC,\%} = \frac{W2 - W3}{W3 - W1} \times 100 \qquad \text{Equation 2}$$

where: W1 − the weight of the container (g), W2 − the weight of moist soil + container (g), and W3 − the weight of dried soil + container (g).

The statistical assessment of the reliability of the differences in the measurement results was carried out using the least significant difference ($LSD_{0.95}$) by comparing the calculated Fisher criterion with the theoretical one. If the calculated criterion is greater than the theoretical one, it is possible to conclude the statistical reliability of the entire experiment.

3. Results and discussion

Studies of the cellulolytic activity of typical chernozem in 2020 showed that the intensity of cellulose-destroying microorganisms was very weak. In the process of estimating the intensity of cellulose decomposition, the dependence of this process on the share of sunflower in crop rotation was revealed. The higher the percentage of crop rotation sunflower saturation is, the higher of the intensity of canvas decomposition. In plots with sunflower crops, there was an increase in cellulolytic activity of the soil in the layer of 10–20 cm by an average of 37% and 20–30 cm by 59% compared to the surface layer of soil of 0–10 cm (Table 2).

In the plot with 60% sunflower saturation, the highest activity of cellulose decomposition was observed in all soil layers. In the arable soil layer (0–30 cm) of this variant, the level of biological activity was 5.1%. Saturation of rotation with grain crops up to 60% and sunflower at 40% causes a decrease in cellulose decomposition activity. In the surface layer of the soil (0–10 cm) it was equal to 2.2%, 10–20 cm – 2.9%, and 20–30 cm – 4.1%. The use of rotation with a share of grain crops up to 80% and sunflower 20% negatively affected the intensity of decomposition of the canvas in all soil layers. Due to the favorable combination of moisture content in the soil in 2021 (compared to 2020) (Table 3) and the availability of sufficient reserves of energy material, the conditions for the activity of microorganisms in all research areas have significantly improved. The crop rotation areas with sunflower saturation from 20 up to 60% had an average intensity of cellulose decomposition with increasing depth of the arable layer. Higher cellulolytic activity of the soil was observed at saturation of crop rotations with sunflower up to 60%.

This indicator is the lowest in the control variant (Table 4). In the plot with clean fallow, the maximum cellulolytic activity of the soil (14.6%) was recorded in the lower (20–30 cm) layer, and in the layers 0–10 and 10–20 cm, this figure decreased to 4.8 and 11.3%, respectively. The highest transformation of plant

Table 2
The intensity of cellulose decomposition in sunflower crops, 2020 (in % to initial weight)

The share of sunflower in crop rotation, %	The intensity of decomposition of the canvas			
	a layer of soil, cm			
	0–10	10–20	20–30	0–30
fallow (control)	1.7	2.1	2.5	2.1
20	2.0	2.9	3.0	2.6
40	2.2	2.9	4.1	3.1
60	3.8	5.6	5.8	5.1
$LSD_{0.95}$	1.9			

Table 3
The moisture of the studied soils (in %)

The share of sunflower in crop rotation, %	Soil moisture							
	a layer of soil, cm							
	the year is 2020				the year is 2021			
	0–10	10–20	20–30	0–30	0–10	10–20	20–30	0–30
fallow (control)	13.4	10.5	15.7	13.2	14.0	17.3	19.6	17.0
20	11.0	14.7	16.4	14.0	15.6	17.7	18.3	17.2
40	11.6	13.3	15.3	13.4	15.5	15.7	18.2	16.4
60	9.8	10.2	14.6	11.5	15.9	17.3	15.5	16.2
$LSD_{0.95}$	0.8				3.15			

Table 4
The intensity of cellulose decomposition in sunflower crops in 2021 (in % to initial weight)

The share of sunflower in crop rotation, %	The intensity of decomposition of the canvas			
	a layer of soil, cm			
	0–10	10–20	20–30	0–30
fallow (control)	4.8	11.3	14.6	10.2
20	8.2	30.2	53.1	30.5
40	41.4	44.4	46.9	44.1
60	43.3	46.5	66.4	52.1
$LSD_{0.95}$	1.2			

residues (66.4%) was recorded in the soil layer of 20–30 cm in the area with crop rotation, where the share of sunflower is 60%. For 45 days, the decrease in tissue weight to the initial in the soil layers 0–10 and 10–20 cm was: 43.3 and 46.5%. In the crop rotation field with 20% sunflower saturation, the intensity of cellulose decomposition was increased from very weak (4.8%) in the soil layer 0–10 cm, weak (11.3%) in the layer 10–20 cm to medium (53.1%) in the soil layer 20–30 cm. On average, over the years of research, the highest intensity of cellulolytic microorganisms in the arable soil layer (0–30 cm) occurred in the field of five-year crop rotation, where the share of sunflower was 60% (28.6%) (Fig. 1). Crop rotations with sunflower saturation of 20 and 40% had a slightly smaller effect on the intensity of cellulose decomposition: 13.3 and 23.6%. The lowest figure was in crop rotation with fallow (6.2%), which can be explained by the low amount of crop residues.

The obtained data coincide with the conclusions of Hepenko (2013), that crop rotations with row crops, which leave behind coarse residues (including sunflower) and slowly decompose provide a high intensity of cellulose decomposition (15.8%). The

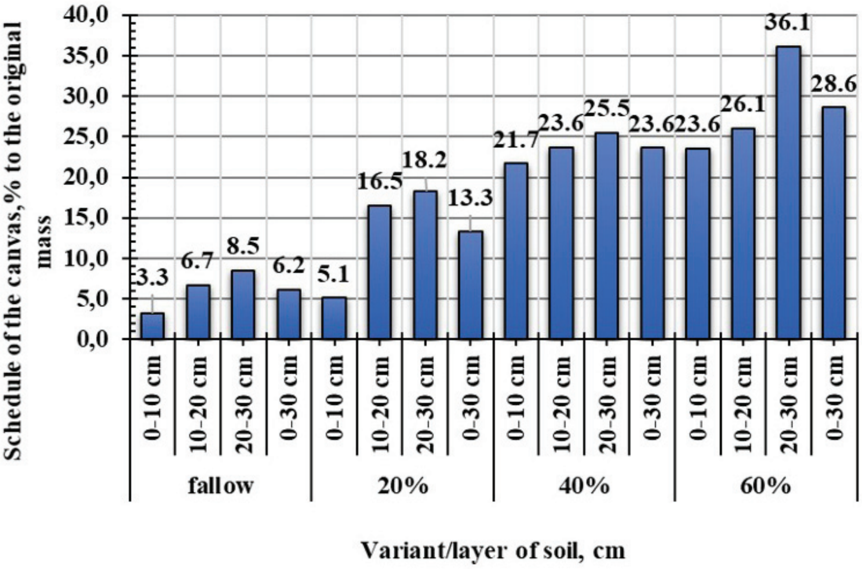

Fig. 1. The intensity of the decomposition of the canvas on average for 2020−2021 (20%, 40%, 60% – the share of sunflower in crop rotation)

lowest cellulolytic activity is revealed in crop rotation with clean fallow (9.4%). In the studies of Kaziuta and Yaremenko (2020), it was shown that cellulose-destroying activity decreases with increasing depth, and this contradicts our data. The maximum cellulose activity (18%) of chernozem under sunflower is revealed in a layer of 0–10 cm. Deeper, this figure decreases two or more times, and cellulose activity is assessed as very weak.

As mentioned above, moisture reserves play an important role in the cellulolytic activity of the soil. Studies have shown that clean fallow and sunflower have different effects on soil moisture (Fig. 2). The crop rotation field with 20% sunflower saturation in the 0–30 cm layer of soil contains a maximum of – 15.6% of moisture. A slightly worse result was observed in a field with clean fallow. In this variant, the arable soil layer was provided with moisture at the level of 15.1%. In the 30-centimeter layer of soil, the least moisture was left after sunflower with a saturation of crop rotation of 40 and 60%: 14.9 and 13.9% respectively. This is because weather conditions (high air temperature and lack of precipitation) cause severe drying of the soil under this crop.

These results are confirmed by data from other researchers. In the case when sunflower occupies 50% of the crop rotation area, the moisture content of the soil layer 0–150 cm is the lowest – 1203 m^3/ha. With a decrease in the share of sunflower from 50.0 to 33.3, 25.0, 20.0, and 14.3% there is an increase in the accumulation of precipitation in the soil, in general on crop rotations, by 47, 49, 42 and 58 m^3/ha (Hanhur, 2019). The activity of soil microbiota is directly proportional to the conditions of moisture in the arable layer (0–30 cm) of soil. There is a tendency to reduce the decomposition of linen fabric with the deterioration of the intra-soil microclimate. This is due to arid conditions with progressive dehydration and compaction of the arable layer of typical chernozem (Tsyliuryk et al., 2017; Tsentylo, 2019).

So, the main principle of creation crop rotations is scientifically based placement and rotation of field crops. Previous research showed that having a higher diversity of crops in a rotation might increase crop productivity through ecological stability and soil resilience (Gaudin et al., 2015; Woźniak and Soroka, 2018). Modern realities are such that the constant cultivation of sunflower in crop rotation is quite often practiced. Most farms abandon the scientifically based technologies of their cultivation for the sake of profit maximization. Nowadays, on most farms, it returns to its previous place after 2−3 years. Mono-cropping exosts soil nutrients and reduces of coefficient nutrient utilization and microbial resistance to environmental changes (Lithourgidis et al., 2006; McDaniel et al., 2014; Li et al., 2019). Studies show that the use of disease-resistant varieties and hybrids can come back the return period of sunflower to five years (Lebid, 2006).

Crop rotation is a major cropping management system used in agroecosystems. Crop rotation is effective due to the improved richness of residual roots and litter in cropping soils which may improve crop yields (Smith et al., 2008). Crop rotations increase soil fertility and tend to promote microbial diversity, and it has been hypothesized that crop rotations can enhance disease suppressive capacity, either through the influence of plant diversity impacting soil bacterial composition or through the increased abundance of disease suppressive microorganisms (Peralta et al., 2018).

Increasing dependence on a small number of crops, such as sunflower, is leading to reductions in agricultural biodiversity (McDaniel et al., 2014). Plant-microbe interactions are not only crucial for a better understanding of plant growth and health but also for sustainable agriculture and environmental protection (Philippot et al., 2013).

The decomposition of cellulose is significantly influenced by hydrothermal conditions, soil structure, the chemical com-

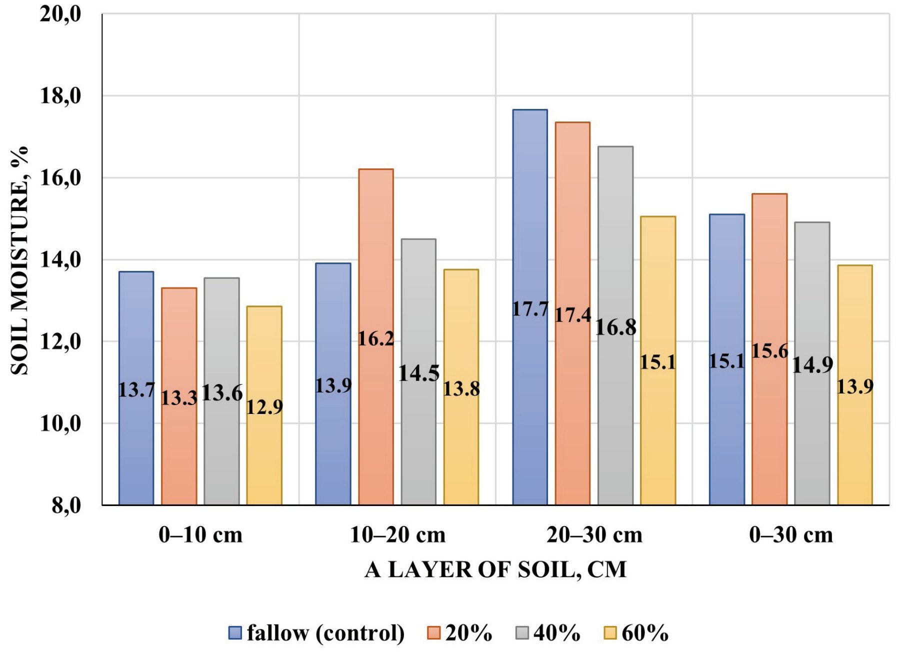

Fig. 2. Moisture reserves in the soil, mm; on average for 2020–2021 (20%, 40%, 60% – the share of sunflower in crop rotation).

position of organic material, and other factors. Soil moisture has a significant impact on the growth and development of crops (Adl, 2003), as well as on the biological activity of the soil (Paul et al., 2003). The temperature of 30°C and moisture of 80–90% out of the total moisture content are the optimal conditions for the mineralization of plant residues (Sozinov and Prister, 1994). Excessive moisture content in the soil leads to increased activity of microorganisms (Kozlowski, 1984; Skopp et al., 1990), and lack of reduces it (Bottner, 1985; Kieft et al., 1987). Temperature is important for the intensity of microbiota development (Snitynskyi et al., 2014). At low temperatures and moisture, the biological decomposition of the substrate slows down, increasing temperature and moisture stimulates its increage. However, high moisture at a favorable temperature can inhibit the aerobic direction of its development (Sozinov and Prister, 1994). At sufficient moisture, but low temperature, the destruction of organic residues also slows down. Significant fluctuations of soil temperature activate the mineralization processes, as the physicochemical properties of water-soluble organic substances change increase (Sozinov and Prister, 1994; Voroney, 2007). The high dependence of cellulolytic activity on weather and climatic conditions is confirmed by correlation analysis (r=0.76) (Prescott et al., 2004; Kovalov et al., 2015). Soil moisture drastically negatively highly is correlated with the variation in amount of microbial which degrade cellulose. Hackl et al. (2005) also found that soil moisture was an important factor of overall microbial activity.

It has been noted in some studies that microorganisms destroy cellulose when moisture is low (Bardgett, 2005). Decreased activity of cellulose-destroying microorganisms is associated with adverse conditions, including high temperatures and low soil moisture. The process of cellulose decomposition is closely related to the biological activity of the soil (Karaca et al., 2010; Stuart Chapin et al., 2009). In this regard, the task of further study of the interrelation between the saturation of short-term crop rotations with sunflower, moisture, and intensity of microbiological processes in the soil remains actual.

4. Conclusions

According to the indicator of the cellulolytic activity of the soil, the possibility of increasing the share of sunflower in short-term crop rotations has been established. Conditions of insufficient soil moisture do not contribute strong cellulose activity. Growing sunflower with an increase in sown area in crop rotation causes the accumulation of coarse residues, thereby increasing the cellulose activity of the soil. At this, the optimal water regime is created by pure steam and sunflower with a share in crop rotation of 20%. However, the cellulose activity of the soil in the field under fallow is low due to the insufficient amount of plant residues, which are used by the microbiome as a nutrient and energy material. Reducing the amount of precipitation negatively affects the intensity of cellulose decomposition in the surface layers of the soil (0–10 cm) and contributes to its high activity in the deeper layers of the soil.

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