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**Review**

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**EFFICIENCY OF DIFFERENT OPTIONS  
OF THE NUTRITION SYSTEM CONCERNING THE INFLUENCE  
ON THE CELLULOLYTIC ACTIVITY OF THE SOIL  
AND THE ACCUMULATION OF POTATO YIELD****V. A. Korol**

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The results of studies of the influence of individual elements of the potato fertilization system of different maturity groups on the cellulolytic activity of grey forestal surface-gleyed coarse-silty light loamy soils on loess-like parent material are presented. It was established that the decomposition of flax fabric depends on the content of available Nitrogen, Phosphorus, Potassium and other trace elements in the soil. The rate of the decomposition process makes it possible to determine the general indicator of the microbiological activity of organisms in the soil. This indicates the participation of all transforming microorganisms in the decomposition processes. Cellulose, as a polysaccharide, leads to the formation of simple sugars during decomposition processes, which serve as the primary source of carbon in the environment. Cellulose chains, connected by hydrogen bonds, contain 44.4 % Carbon, 6.17 % Hydrogen and 49.4 % Oxygen. Cellulolytic organisms provide Carbon sources to increase soil fertility and maintain nutrient balance by accelerating residue decomposition processes. The lowest cellulolytic activity of flax decomposition was observed in the control variant, i.e., without using any fertilizers. It amounted to 46.2 and 49.8 %, respectively, for the early-ripening potato variety Slauta and the mid-ripening variety Lehenda. The most intensive decomposition of flax occurred in variants with the application of dry granulated chicken manure (0.5 t/ha) and biohumus fertilizer (4.0 t/ha). Accordingly, in the Slauta potato variety, these indicators were 70.4 and 71.5 % and exceeded the control variant by 22.4 and 23.8 %. For the mid-ripening potato variety Legend, when applying the above fertilizers, the excess over the control variant was 21.3 and 24.1 % and amounted to 71.2 and 73.9 % of cellulolytic activity, respectively.

**Keywords:** potato, fertilization, cellulolytic activity, microorganisms, organic fertilizers.

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## Ефективність різних варіантів системи живлення щодо впливу на целюлозолітичну активність ґрунту та накопичення урожайності картоплі

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Наведено результати досліджень впливу окремих елементів системи удобрення картоплі різних груп стиглості на целюлозолітичну активність сірих лісових поверхневооглеєних крупнопилувато-легкосуглинкових ґрунтів на лесоподібних відкладах. Встановлено, що розкладання лляної тканини залежить від вмісту в ґрунті доступних форм азоту, фосфору і калію та інших мікроелементів. За швидкістю процесу розкладання можливе визначення загального показника мікробіологічної діяльності організмів у ґрунті і це свідчить про участь усіх мікроорганізмів-трансформерів у процесах розкладання. Целюлоза, як полісахарид за процесів розкладання призводить до утворення простих цукрів, що служать первинним джерелом вуглецю в навколишньому середовищі. Целюлозні ланцюги, що з'єднані водневими зв'язками містять 44,4 % вуглецю 6,17 % водню та 49,4 % кисню. Целюлозолітичні організми забезпечують постачання джерел вуглецю задля підвищення родючості ґрунтів та підтримки балансу поживних речовин через пришвидшення процесів розкладання залишків. Целюлозоруйнуюча активність розкладання лляного полотна за найнижчих показників відмічалась на контрольному варіанті, тобто без застосування будь-яких добрив і становила 46,2 та 49,8 % відповідно ранньостиглого сорту картоплі Слаута та середньостиглого сорту Легенда. Найбільш інтенсивне розкладання лляного полотна відбувалося на варіантах з внесенням сухого гранульованого курячого посліду (0,5 т/га) та добрива біогумус (4,0 т/га). Відповідно у сорту картоплі Слаута ці показники склали 70,4 та 71,5 % та перевищили контрольний варіант на 22,4 та 23,8 %. Для середньостиглого сорту картоплі Легенда за внесення вище наведених доз добрив перевищення контрольного варіанту було на 21,3 та 24,1 відсотка і відповідно складало 71,2 та 73,9 відсотка целюлозоруйнуючої активності.

**Ключові слова:** картопля, удобрення, целюлозоруйнуюча активність, мікроорганізми, органічні добрива.

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**Introduction.** Organic farming is based on the sustainable replenishment of soils with organic matter through the introduction and use of green manure crops, organic fertilizers, crop by-products and root residues since organic matter is the source of energy for soil microbiota nutrition. The latter transforms organic matter into humus substances and creates conditions most conducive to the fixation of atmospheric nitrogen by nodule bacteria. These processes contribute to improving the activity of beneficial microflora in the soil and increase the mobilization of hard-to-reach forms of phosphorus [1].

The biological activity of the soil can be characterized by the amount of flax tissue decomposed by microorganisms during the potato growing season under different fertilization options in the soil layer where the mother tubers are located, along with most of the applied fertilizers.

The activity of cellulolytic microorganisms in the soil depends on many factors, namely the temperature and pH of the soil solution, soil structure, the chemical and qualitative composition of organic residues and fertilizers applied, and their distribution along the profile. These aspects enable the use

of cellulolytic activity to assess biological indicators of the soil when using various types of mineral and organic fertilizers [13, 21].

The decomposition of fibre, namely flax tissue, depends on the content of nitrogen, phosphorus, potassium and other essential trace elements in the soil, and therefore, its decomposition rate can determine the overall biological activity of microorganisms in the soil. This indicator can also reflect the level of general microbiological activity since all microorganisms that transform organic compounds participate in the decomposition process [5, 11].

Organic matter and soil enzymatic activity directly affect fertility. The dominant component of soil organic matter, plant residues and organic fertilizers is cellulose, which is one of the main links in the chain of transformation of organic compounds in the soil. Cellulase is an enzyme that catalyzes the hydrolysis of beta (1,4)-glycosidic bonds with the formation of glucose or cellobiose, i.e. it splits the cellulose molecule into monosaccharides.

The enzyme is well studied, but it continues to attract interest because cellulase and the microorganisms that synthesize it play a significant role in the carbon cycle, namely the release of CO<sub>2</sub> into the atmosphere. Therefore, cellulase activity is studied by different methods in different soils and under different conditions, and since cellulase directly affects the rate of decomposition of plant residues, studying the activity of this enzyme is a priority task when researching the biological activity of soils of agrocenoses [10, 16, 24].

Cellulose is a polysaccharide with the formula (C<sub>6</sub>H<sub>5</sub>O<sub>10</sub>)<sub>n</sub>, where n varies from 500 to 5000, depending on the polymer's origin. It consists of a linear chain of several hundred to more than ten thousand β (1→4) linked D-glucose units. Cellulose chains, connected by hydrogen bonds and Van der Waals forces, form fibrils and mainly contain Carbon (44.44 %), Hydrogen (6.17 %) and Oxygen (49.39 %) [24].

Decomposition leads to the formation of simple sugars, which are used by the soil

edaphon as the primary carbon source in the environment. Microorganisms that produce cellulase enzyme complex possess the ability to decompose cellulose. Cellulolytic enzymes, called cellulases, are enzymes that hydrolyze cellulose, thus forming water and soluble sugar [22, 23].

Fungi are well-known agents in decomposition of organic matter in general and cellulose substrate in particular [17]. There are many reports of the production of fungal cellulase, but only a few of them have proven high activity [5]. Under aerobic conditions, cellulose is decomposed by fungi such as *Trichoderma*, *Penicillium*, *Aspergillus*, *Fusarium* and *Rhizopus* [19, 25, 28]. The most active producers of cellulolytic enzymes were *Aspergillus terreus* and *Aspergillus niger* [15].

After the initial loosening of the material, further transformations are carried out by, among others, the following bacterial species: *Cellulomonas*, *Streptomyces* and *Micromonospora* [13, 14, 20].

The cellulolytic properties of some bacterial genera, such as *Cellvibrio*, *Pseudomonas*, *Micrococcus*, *Sporocytophaga* and species such as *Bacillus cereus*, *Bacillus subtilis*, *Paenibacillus amylolyticus*, *Pseudomonas fluorescens* and *Serratia marcescens* have also been reported [12, 18].

The product of the decomposition is cellobiose and even glucose; coloured compounds are often produced with uronic acids and proteins. Under anaerobic conditions, cellulose is degraded by bacteria of the genus *Clostridium*. However, methanogenic archaea are involved in cellulose degradation in environments where oxygen access is difficult.

Cellulolytic microorganisms provide carbon sources to increase soil fertility and maintain nutrient balance in the ecological system by decomposing cellulose residues.

The study aims to analyze the impact of different fertilizers on the cellulose-destructive activity of soil and potato yield, particularly to assess the effectiveness of organic and mineral fertilizers of varying composition and their combinations.

**Materials and methods.** The study was carried out on the fields of a four-field crop rotation at the Department of Crop Breeding of the Institute of Agriculture of Carpathian Region of the National Academy of Sciences of Ukraine, in Obroshyne village, Lviv district, Lviv region. Winter grains were sown as a preceding crop for potatoes with post-harvest sowing of green manure crops.

Mineral fertilizers were applied in the form of nitroammophoska ( $N_{16}P_{16}K_{16}$ ); potassium magnesia ( $K_{28}Mg_8S_{15}$ ) was used to balance the deficiency of Potassium and Magnesium.

The soils used in the experiment were grey forestal surface-gleyed coarse-silty light loamy on loess-like parent material. They are heterogeneous in terms of their mechanical composition, and their moisture regime largely depends on this factor. The upper horizons have higher moisture level compared to the lower ones. For this reason, soils in rainy seasons or years with much precipitation are subject to excessive moisture and gleying. In dry years, they are sufficiently provided with productive moisture. In addition, gleying is also significantly influenced by groundwater, the depth of which is within 1.3–1.5 m.

Based on the agrochemical analyses conducted, it was found that the experimental soils were low in humus (1.58–1.67 %), have an acidic reaction of the soil solution (pH 4.80–5.17), the sum of absorbed bases was 6.20–7.22, the hydrolytic acidity was 2.87–3.29 mg-eq per 100 g of soil.

The scheme of the experiment included the following options: control without fertilizers; manure (40 t/ha) with the addition of the recommended dose of mineral fertilizers ( $N_{90}P_{90}K_{120}$ ); recommended dose of mineral fertilizers ( $N_{90}P_{90}K_{120}$ ); manure (40 t/ha); dry granulated chicken manure (0.5 t/ha), Biohumus fertilizer (4.0 t/ha) and Bioactive fertilizer (8.0 t/ha), which were applied locally.

The research was conducted using methodological approaches used in international practice and met the standards of the State Standards of Ukraine and the requirements of ISO 17025. The experiment

design, plot size and replication methods were guided by: “Potato Growing: Research Methodology”, “Methodology for Evaluating Potato Varieties for Resistance to Major Pests and Diseases”, “Methodology of Scientific Research in Agronomy”, “Fundamentals of Scientific Research”, “Potato Growing: A Manual”, “Methodological Recommendations for Conducting Research with Potatoes” and “Methodological Guidelines for Implementing the Requirements of the Global G.A.P. Standard in Potato Growing. USAID Project “Support to Agrarian and Rural Development” [2–4, 6–9, 11–14, 16].

**Results and discussion.** Based on the obtained in the research data and statistical processing ( $HIP_{05} = 0.33–0.45$ ;  $HIP_{05} = 0.52–0.40$ ) by comparing the reliability of deviations between the variants of the experiment and their interaction, it can be concluded that the cellulolytic activity of grey forestal surface-gleyed soil varied depending on the type of fertilizer studied in the research. The lowest cellulolytic activity was noted in the control variant without fertilizers. It amounted to 46.2 and 49.8 % for the early-ripening potato variety Slauta and the mid-ripening variety Lehenda, respectively (Table 1).

The application of organo-mineral fertilizers in the recommended dose for the Western Forest-Steppe (40 t/ha of manure and  $N_{90}P_{90}K_{120}$ ) led to an intensification of microbiological and biochemical processes in the soil, which in turn contributed to the active action of cellulose-degrading microorganisms. In this variant, the decomposition of linen fabric was quite intensive. For the early-ripening variety Slauta the decomposition rate was 59.9 %, and for the mid-ripening Lehenda it reached 70.4, exceeding control by 12.3 and 20.6 %, respectively.

The most intensive decomposition of linen fabric occurred in variants with dry granulated chicken manure (0.5 t/ha) and biohumus fertilizer (4.0 t/ha). For the potato variety Slauta, the decomposition rates were 70.7 and 70.1 % and exceeded the control variant by 22.4 and 23.8 %.

### 1. The influence of elements of the fertilizer system on the intensity of flax linen decomposition during the cultivation of potatoes of different maturity groups, %\*

| Research options   | Year of research |      | Average of 2023–2024 |
|--|------------------|------|----------------------|
|  | 2023             | 2024 |                      |
| v. Slauta  |                  |      |                      |
| Without fertilizer (control)   | 49.6             | 42.9 | 46.2                 |
| Manure, 40 t/ha + N <sub>90</sub> P <sub>90</sub> K <sub>120</sub>           | 70.8             | 50.2 | 60.5                 |
| Recommended fertilizer dose N <sub>90</sub> P <sub>90</sub> K <sub>120</sub> | 54.6             | 58.7 | 56.6                 |
| Manure, 40 т/га  | 67.8             | 66.5 | 67.1                 |
| Granulated chicken manure, 0.5 t/ha  | 70.7             | 70.1 | 70.4                 |
| Biohumus, 4.0 t/ha (locally)   | 72.1             | 70.9 | 71.5                 |
| Bioactive, 8.0 t/ha (locally)  | 56.8             | 57.5 | 57.1                 |
| HIP <sub>05</sub>  | 0.33             | 0.45 | 0.33–0.45            |
| v. Lehenda   |                  |      |                      |
| Without fertilizer (control)   | 50.1             | 49.5 | 49.8                 |
| Manure, 40 t/ha + N <sub>90</sub> P <sub>90</sub> K <sub>120</sub>           | 71.2             | 70.3 | 70.7                 |
| Recommended fertilizer dose N <sub>90</sub> P <sub>90</sub> K <sub>120</sub> | 55.0             | 56.4 | 55.7                 |
| Manure, 40 т/га  | 68.0             | 67.3 | 67.6                 |
| Granulated chicken manure, 0.5 t/ha  | 70.9             | 71.5 | 71.2                 |
| Biohumus, 4.0 t/ha (locally)   | 73.8             | 74.1 | 73.9                 |
| Bioactive, 8.0 t/ha (locally)  | 58.0             | 57.3 | 57.6                 |
| HIP <sub>05</sub>  | 0.52             | 0.40 | 0.52–0.40            |

\*Note: Exposure time 30 days.

For the mid-ripening potato variety Legend, the application of these fertilizers resulted in 21.3 and 23.8 % higher decomposition rate than the control, with overall cellulose-degrading activity reaching 70.9 and 71.5 %.

Analysis of potato yield on the 70th day after planting in the variant without fertilizers (control) in the Slauta variety with an average

weight of tubers per bush of 0.350 kg, the yield was 19.3 t/ha, respectively, for the Lehenda variety, the yield indicator was 18.9 t/ha with a tuber weight of 0.343 kg. It should be noted that compared to the yield on the 60th day, relative to the Slauta variety, it slightly decreased by 1.9 t/ha, and relative to the Lehenda variety, it increased by 0.5 t/ha (Table 2).

### 2. Potato yield on the 70th day after planting depending on the dose of applied fertilizers on average for the years of the study (2023–2024)

| Variants of the experiment   | Slauta               |             | Lehenda              |             |
|--|----------------------|-------------|----------------------|-------------|
|  | weight of tubers, kg | yield, t/ha | weight of tubers, kg | yield, t/ha |
| Without fertilizers (control)  | 0.350                | 19.3        | 0.343                | 18.9        |
| Manure, 40 t/ha + N <sub>90</sub> P <sub>90</sub> K <sub>120</sub>               | 0.577                | 31.7        | 0.423                | 23.2        |
| Recommended dose of fertilizers N <sub>90</sub> P <sub>90</sub> K <sub>120</sub> | 0.350                | 19.2        | 0.334                | 18.4        |
| Manure, 40 t/ha  | 0.690                | 38.0        | 0.436                | 24.0        |
| Granulated chicken manure, 0.5 t/ha  | 0.560                | 30.8        | 0.483                | 26.7        |
| Biohumus, 4.0 t/ha (locally)   | 0.467                | 25.6        | 0.523                | 28.8        |
| Bioactive, 8.0 t/ha (locally)  | 0.415                | 22.8        | 0.347                | 19.1        |
| HIP <sub>05</sub>  |                      | 6.8–7.4     |                      | 11.4–12.0   |

In the variant applying the recommended dose of fertilizers (manure + N<sub>90</sub>P<sub>90</sub>K<sub>120</sub>) for the Slauta variety, the tuber weight and yield indicators were 0.557 kg and 31.7 t/ha. They were higher than during the first dynamic digging by 0.034 kg and 1.9 t/ha. Accordingly, in the Lehenda variety, the tuber weight was 0.423 kg, and the yield was 23.2 t/ha, which remained at the same level as on the 60th day of vegetation.

By conducting dynamic digging on the 70th day, it was established that the highest yield rate in the Slauta variety was observed when 40 t/ha of manure was applied and amounted to 38.0 t/ha. However, it was also relatively high when granulated chicken manure was applied at a dose of 0.5 t/ha and amounted to 30.8 t/ha of potato tubers.

Accordingly, the highest yield of the Legend variety was observed when applying bio-humus fertilizer, which amounted to 28.8 t/ha. However, it was also relatively high

when fertilizing with granulated chicken manure (0.5 t/ha) – 26.8 t/ha with a tuber weight of one bush of 0.523 kg.

In all other variants of the experiment with the Slauta variety, with different doses of fertilizers, the weight of tubers ranged from 0.350 to 0.467 kg, and the yield was 19.2–25.6 t/ha. Accordingly, for the Lehenda variety, the weight of tubers and yield was from 0.334 to 0.436 kg, and the yield was 18.4–24.0 t/ha.

**Conclusions.** Changes in the quantity and quality of mineral and organic fertilizers applied to the soil, using a wide range of plant protection products, and intensive tillage of the soil negatively affect microbiological and enzymatic activity. As a result, a significant change in soil forming processes occurs, which in turn is reflected in the content of nutrients and humus.

#### Список використаної літератури

1. Виробництво та використання органічних добрив : монографія / І. А. Шувар та ін. ; за заг. ред. І. А. Шуvara. Івано-Франківськ : Симфонія форте, 2015. 596 с.
2. Картоплярство : методика дослідної справи / за ред. А. А. Бондарчука, В. А. Колтунова. Вінниця : ТОВ «Твори», 2019. 652 с.
3. Картоплярство : навч. посіб. / І. О. Федосій та ін. Київ : ФОП Ямчинський, 2022. 382 с.
4. Картоплярство : селекція / за ред. А. А. Бондарчука, Т. М. Олійник. Вінниця : ТОВ «ТВОРИ», 2020. 624 с.
5. Методика наукових досліджень в агрономії : навч. посіб. / В. Г. Дідора та ін. Київ : Центр учбової літератури, 2013. 264 с. [http://ir.polissiauniver.edu.ua/bitstream/123456789/3892/1/MNDA\\_2013\\_73-86.pdf](http://ir.polissiauniver.edu.ua/bitstream/123456789/3892/1/MNDA_2013_73-86.pdf).
6. Методика наукових досліджень в агрономії / Е. Р. Ермантраут та ін. Біла Церква, 2018. 104 с.
7. Методичні настанови з впровадження вимог стандарту Global g.a.p. у картоплярстві. Проєкт USAID «Підтримка аграрного та сільського розвитку». Київ, 2018. 80 с.
8. Методологія оцінювання сорторазків картоплі на стійкість проти основних шкідників і збудників хвороб / С. О. Трибель та ін. ; за наук. ред. С. О. Трибеля і А. А. Бондарчука. Київ : Аграрна наука, 2013. 264 с.
9. Основи наукових досліджень в агрономії : навч. посібник / В. М. Положенець та ін. Житомир ПП «Рута», 2024. 168 с. <https://repo.btu.kharkov.ua/handle/123456789/60064>.

#### References

1. Production and use of organic fertilizers : monograph / I. A. Shuvar et al.; za zah. red. I. A. Shuvara. Ivano-Frankivsk : Symfoniia forte, 2015. 596 p.
2. Potato growing: a method of research / za red. A. A. Bondarchuka, V. A. Koltunova. Vinnytsia : TOV «Tvory», 2019. 652 p.
3. Potato growing: a textbook / I. O. Fedosiy et al. 2022. 382 p.
4. Potato growing : breeding / za red. A. A. Bondarchuka, T. M. Oliinyk. Vinnytsia : TOV «TVORY», 2020. 624 p.
5. Methods of scientific research in agronomy : textbook / V. H. Didora et al. Kyiv : Tsentr uchbovoi literatury, 2013. 264 p. [http://ir.polissiauniver.edu.ua/bitstream/123456789/3892/1/MNDA\\_2013\\_73-86.pdf](http://ir.polissiauniver.edu.ua/bitstream/123456789/3892/1/MNDA_2013_73-86.pdf)
6. Methodology of scientific researches in agronomics / E. R. Ermantraut. Bila Tserkva, 2018. 104 p.
7. The methodical instructions is from introduction of requirements of standard Global of g.a.p. in potato growing. A project of USAID «Support of agrarian and rural development». Kyiv, 2018. 80 p.
8. Methodology of evaluation of potato variety-samples on resistance against basic pests and causative agents of diseases / S. O. Trybel et al.; za nauk. red. S. O. Trybel and A. A. Bondarchuka. Kyiv : Ahrarna nauka, 2013. 264 p.
9. Fundamentals of scientific research in agronomy / V. M. Polozhenets et al. Zhytomyr

10. Activation Energy of Extracellular Enzymes in Soils from Different Biomes / J. M. Steinweg et al. *PLoS ONE*. 2013. Vol. 8 (3): e59943. <https://doi.org/10.1371/journal.pone.005994>.
11. Dadwal A., Sharma S., Satyanarayan T. Diversity in Cellulose-Degrading Microbes and Their Cellulases: Role in Ecosystem Sustainability and Potential Applications. *Microbial Diversity in Ecosystem Sustainability and Biotechnological Applications (Soil & Agroecosystems)*. Singapore. 2019. Vol. 2. P. 375–402. [https://doi.org/10.1007/978-981-13-8487-5\\_15](https://doi.org/10.1007/978-981-13-8487-5_15).
12. Bhat M. K. Cellulases and related enzymes in biotechnology. *Biotechnol. Advanc.* 2000. Vol. 18 (5). P. 355–383. <https://pubmed.ncbi.nlm.nih.gov/14538100/>.
13. Deng S. P., Tabatabai M. A. Cellulase activity of soils. *Soil Bio. Biochem.* 1994. Vol. 26 (10). P. 1347–1354. <https://www.sciencedirect.com/science/article/abs/pii/S003807179490216X>.
14. Effect of different growth parameters on endoglucanase enzyme activity by bacteria isolated from coir retting effluents of estuarine environment / G. Immanuel et al. *Int J. Environ. Sci. Technol.* 2006. Vol. 3 (1). P. 25–34. <https://link.springer.com/article/10.1007/BF03325904>.
15. Isolation, purification and enzymatic activity of cellulase components the fungus *Aspergillus terreus* / S. Y. Mirzaakhmedov et al. *Chem. Nat. Compd.* 2007. Vol. 43 (5). P. 594–597. DOI: 10.1007/s10600-007-0199-6.
16. Krzyśko-Łupicka T., Kręcidło Ł., & Kręcidło M. The Comparison of Cellulolytic Activity of the Modified Soil Treated with Roundup. *Chemistry-Didactics-Ecology-Metrology*. 2016. Vol. 21 (1–2). P. 133–139. <https://doi.org/10.1515/cdem-2016-0012>.
17. Microbial cellulose utilization: fundamentals and biotechnology / L. R. Lynd et al. *Microbiol. Mol. Biol. Rev.* 2002. Vol. 66. P. 506–577. DOI: 10.1128/MMBR.66.3.506-577.2002.
18. Novel substrate specificity of a membrane-bound beta-glycosidase from the hyperthermophilic archaeon *Pyrococcus horikoshii* / I. Matsui et al. *Fed. Europ. Biochem. Soc. Lett.* 2000. Vol. 467. P. 195–200. DOI: 10.1016/S0014-5793(00)01156-X.
19. Nutrient effects on production of cellulolytic enzymes by *Aspergillus niger* / G. Narasimha et al. *Afr. J. Biotechnol.* 2006; Vol. 5 (5). P. 472–476. DOI: 10.5897/AJB05.224.
20. Optimization of cellulase production from bacteria isolated from soil / S. Sethi et al. *Int. Scholarly. Res. Notices Biotechnol.* 2013. DOI: 10.5402/2013/985685.
21. Pavel R., Doyle J., Steinberge Y. Seasonal patterns of cellulase concentration in desert soil. *Soil Biology and Biochemistry*. 2004. Vol. 36 (3). P. 549–554. <https://doi.org/10.1016/j.soilbio.2003.10.024>.
22. Rapa P., Beermann A. Bacterial cellulase. In: Biosynthesis and Biodegradation of Cellulose. *Haigler CH, Weimer PJ, editors*. New York : Marcel Dekker. 1991. P. 535–599.
- PP «Ruta», 2024. 168 p. <https://repo.btu.kharkov.ua/handle/123456789/60064>.
10. Activation Energy of Extracellular Enzymes in Soils from Different Biomes / J. M. Steinweg et al. *PLoS ONE*. 2013. Vol. 8 (3): e59943. <https://doi.org/10.1371/journal.pone.005994>.
11. Dadwal A., Sharma S., Satyanarayan T. Diversity in Cellulose-Degrading Microbes and Their Cellulases: Role in Ecosystem Sustainability and Potential Applications. *Microbial Diversity in Ecosystem Sustainability and Biotechnological Applications (Soil & Agroecosystems)*. Singapore. 2019. Vol. 2. P. 375–402. [https://doi.org/10.1007/978-981-13-8487-5\\_15](https://doi.org/10.1007/978-981-13-8487-5_15).
12. Bhat M. K. Cellulases and related enzymes in biotechnology. *Biotechnol. Advanc.* 2000. Vol. 18 (5). P. 355–383. <https://pubmed.ncbi.nlm.nih.gov/14538100/>.
13. Deng S. P., Tabatabai M. A. Cellulase activity of soils. *Soil Bio. Biochem.* 1994. Vol. 26 (10). P. 1347–1354. <https://www.sciencedirect.com/science/article/abs/pii/S003807179490216X>.
14. Effect of different growth parameters on endoglucanase enzyme activity by bacteria isolated from coir retting effluents of estuarine environment / G. Immanuel et al. *Int J. Environ. Sci. Technol.* 2006. Vol. 3 (1). P. 25–34. <https://link.springer.com/article/10.1007/BF03325904>.
15. Isolation, purification and enzymatic activity of cellulase components the fungus *Aspergillus terreus* / S. Y. Mirzaakhmedov et al. *Chem. Nat. Compd.* 2007. Vol. 43 (5). P. 594–597. DOI: 10.1007/s10600-007-0199-6.
16. Krzyśko-Łupicka T., Kręcidło Ł., & Kręcidło M. The Comparison of Cellulolytic Activity of the Modified Soil Treated with Roundup. *Chemistry-Didactics-Ecology-Metrology*. 2016. Vol. 21 (1–2). P. 133–139. <https://doi.org/10.1515/cdem-2016-0012>.
17. Microbial cellulose utilization: fundamentals and biotechnology / L. R. Lynd et al. *Microbiol. Mol. Biol. Rev.* 2002. Vol. 66. P. 506–577. DOI: 10.1128/MMBR.66.3.506-577.2002.
18. Novel substrate specificity of a membrane-bound beta-glycosidase from the hyperthermophilic archaeon *Pyrococcus horikoshii* / I. Matsui et al. *Fed. Europ. Biochem. Soc. Lett.* 2000. Vol. 467. P. 195–200. DOI: 10.1016/S0014-5793(00)01156-X.
19. Nutrient effects on production of cellulolytic enzymes by *Aspergillus niger* / G. Narasimha et al. *Afr. J. Biotechnol.* 2006; Vol. 5 (5). P. 472–476. DOI: 10.5897/AJB05.224.
20. Optimization of cellulase production from bacteria isolated from soil / S. Sethi et al. *Int. Scholarly. Res. Notices Biotechnol.* 2013. DOI: 10.5402/2013/985685.
21. Pavel R., Doyle J., Steinberge Y. Seasonal patterns of cellulase concentration in desert soil. *Soil Biology and Biochemistry*. 2004. Vol. 36 (3). P. 549–554. <https://doi.org/10.1016/j.soilbio.2003.10.024>.

23. Russel S., Górski E. B., Wyczółkowski A. I. Enzymes taking part in hydrolysis of cellulose : monograph. *Acta Agrophysica*. 2005. Vol. 3. P. 27–36. <http://www.old.acta-agrophysica.org/en/monograph.html?stan=detail&paper=518>.

24. Sinegani A. A., Sinegani M. S. Adsorption, immobilization and activity of cellulase in soil: the impacts of maize straw and its humification. *Brazilian Archives of Biology and Technology*. 2013. Vol. 56. P. 885–894. DOI: 10.1590/S1516-89132013005000006.

25. Sri Lakshmi A., Narasimha G. Production of cellulases by fungal cultures isolated from forest litter soil. *Ann For Res*. 2012. Vol. 55 (1). P. 85–92. <http://www.editurasilvica.ro/afr/55/1/narasimha.pdf>.

26. The effect of chemical composition on microfibrillar cellulose films from wood pulps: mechanical processing and physical properties / K. L. Spence et al. *Biores. Technol*. 2020. Vol. 101. P. 5961–5968. DOI: 10.1016/j.biortech.2020.02.104.

27. Updegraff D. M. Semimicro determination of cellulose in biological materials. *Anal. Biochem*. 1969. Vol. 32 (3). P. 420–424. DOI: 10.1016/S0003-2697(69)80009-6.

28. Vries R. P., Visser J. *Aspergillus* enzymes involved in degradation of plant cell wall polysaccharide. *Microbiol. Mol. Biol. Rev*. 2001. Vol. 65 (4). P. 497–522. DOI: 10.1128/MMBR.65.4.497-522.2001.

Rapa P., Beermann A. Bacterial cellulase. In: Biosynthesis and Biodegradation of Cellulose. *Haigler CH, Weimer PJ, editors*. New York : Marcel Dekker. 1991. P. 535–599.

23. Russel S., Górski E.B., Wyczółkowski A. I. Enzymes taking part in hydrolysis of cellulose : monograph. *Acta Agrophysica*. 2005. Vol. 3. P. 27–36. <http://www.old.acta-agrophysica.org/en/monograph.html?stan=detail&paper=518>.

24. Sinegani A. A., Sinegani M. S. Adsorption, immobilization and activity of cellulase in soil: the impacts of maize straw and its humification. *Brazilian Archives of Biology and Technology*. 2013. Vol. 56. P. 885–894. DOI: 10.1590/S1516-89132013005000006.

25. Sri Lakshmi A., Narasimha G. Production of cellulases by fungal cultures isolated from forest litter soil. *Ann For Res*. 2012. Vol. 55 (1). P. 85–92. <http://www.editurasilvica.ro/afr/55/1/narasimha.pdf>.

26. The effect of chemical composition on microfibrillar cellulose films from wood pulps: mechanical processing and physical properties / K. L. Spence et al. *Biores. Technol*. 2020. Vol. 101. P. 5961–5968. DOI: 10.1016/j.biortech.2020.02.104.

27. Updegraff D. M. Semimicro determination of cellulose in biological materials. *Anal. Biochem*. 1969. Vol. 32 (3). P. 420–424. DOI: 10.1016/S0003-2697(69)80009-6.