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INCREASING EFFICIENCY OF SOIL BIOREMEDIATION

I.V. Kokunova, A.A. Zhukov, T.E. Fedorova-Semenova

The intensification of agricultural production and processing industries, the use of powerful tractors and harvesters, and the increase in the intensity of road cargo transportation lead to an increase in waste from economic activities and an increase in the anthropogenic load on the environment. Human-made accidents exacerbate the problems of the stability of natural ecosystems. Dangerous substances get into the soil and accumulate in it in the form of various toxicants. This situation poses a threat to all living organisms. One of the ways to solve the urgent problems of environmental safety and the production of high-quality agricultural products is the use of bioremediation technologies for soil purification. The paper aims to increase the efficiency of soil bioremediation technology by improving the technical means used for the aeration of soil piles. The current aerators-mixers perform soil agitation and grinding of large soil formations while saturating the treated material with oxygen. We propose improving the stirring drum design of a semi-suspended aerator-mixer, equipping it with new knife-shaped working blades and with a screw winding that allows increasing the contact area with the processed mass and forming a pile of a given shape. The contact surface increases due to biological products sprayed by the nozzles and the fine soil fraction formed after treatment. This fact also intensifies the microbiological processes of toxicant oxidation. Based on the theoretical research and multivariate regression analysis, we obtained a regression equation. It allowed us to establish the relationship between the main factors that affect the aeration process of soil piles to a greater extent. We carried out experimental studies in the scientific laboratories of the university. Thus, we determined the rational parameters of the improved aerator-mixer of piles.

Keywords: *soil toxicants; bioremediation; organic compost; soil restoration technology; reproduction of natural resources; aerator-mixer of piles*

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ БИОРЕМЕДИАЦИИ ПОЧВ

И.В. Кокунова, А.А. Жуков, Т.Е. Федорова-Семенова

Интенсификация сельскохозяйственного производства и перерабатывающих отраслей промышленности, применение мощных тракторов и уборочных комбайнов, увеличение интенсивности автомобильных грузоперевозок приводят к увеличению отходов от хозяйственной деятельности и усилению антропогенной нагрузки на окружающую природную среду. Возникающие техногенные аварии еще в большей степени обостряют проблемы устойчивости природных экосистем. Опасные вещества, попадая в почву, аккумулируются в ней в виде разнообразных токсикантов, что представляет угрозу для всех живых организмов. Одним из путей решения актуальных проблем экологической безопасности и производства качественной сельскохозяйственной продукции является применение биоремедиационных технологий очистки почв. Цель данного исследования – повышение эффективности технологии биоремедиации почв путем совершенствования технических средств, используемых для аэрации почвенных буртов. Применяемые сегодня аэраторы-смесители выполняют ворошение почвы и измельчение крупных почвенных образований, насыщая при этом обрабатываемый материал кислородом. Предлагается усовершенствовать конструкцию ворошительного барабана полунавесного аэратора-смесителя, оснастив его не только новыми рабочими лопастями ножевидной формы, но и шнековой навивкой, позволяющей увеличить площадь контакта с обрабатываемой массой и формировать бурт заданной формы. Распыляемые форсунками биопрепараты и образующаяся после обработки мелкая почвенная фракция способствуют увеличению поверхности соприкосновения, что также интенсифицирует микробиологические процессы окисления токсиканта. На основе проведенных теоретических изысканий и многофакторного регрессионного анализа получено уравнение регрессии, позволяющее установить зависимость между основными факторами, влияющими в большей степени на процесс аэрации почвенных буртов. Проведенные в научных лабораториях университета экспериментальные исследования позволили определить рациональные параметры усовершенствованного аэратора-смесителя буртов.

Ключевые слова: *почвенные токсиканты; биоремедиация; органические компосты; технология восстановления почв; воспроизводство природных ресурсов; аэратор-смеситель буртов*

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Introduction

The implementation of plans aimed at (1) solving the most vital tasks of ensuring the country's food security, (2) innovative modernization of the agro-industrial complex, and (3) import substitution in various sectors of the economy lead to an increase in the volume of products produced and in waste from economic activities and an increase in the anthropogenic load on the environment. These factors directly impact slowing down the processes of self-purification and self-healing of the natural ecosystem.

Many Russian and foreign researchers [7; 12; 17; 18] note that recently there has been a noticeable destabilization of the terrestrial ecosystem, including soil. Therefore, currently, improving the efficiency of technologies for restoring polluted soils is an urgent task for science and practice. When deciding on the restoration of contaminated soils, one should consider that the currently used methods and methods of purification can differ significantly due to the variety of possible contamination, territorial and climatic features of the regions.

One of the ways to solve the urgent problem of the sustainability of natural and natural-anthropogenic systems is the use of bioremediation technologies for soil purification [6; 10]. Bioremediation technology involves using a complex of methods for soil purification based on the use of the biochemical potential of microorganisms capable of metabolizing a considerable number of different organic substances [11; 19]. As a result of the ongoing purification processes, there is no formation of secondary waste, which is characteristic of other remediation methods of purification. Thus, the main advantage of this technology is its safety for the natural environment.

The currently used international classification of bioremediation technologies divides them into three enlarged groups:

- Bioremediation *ex situ* – extraction of contaminated soil, its transfer to special sites for disinfection, performing agrotechnical works, and returning the restored soil to its former place;
- Bioremediation *on situ* – carrying out all routine maintenance work with the use of biological products-destructors on the spot;
- Bioremediation *in situ* – cleaning of contaminants located under the soil surface, based on the methods of bioventilation, biosparging, or biodestruction [9; 11].

Any equipment used for the aerobic process of bioremediation and biocomposting aims to provide the most favorable conditions for the microbiological oxidation of the toxicant. If this process is located in a favorable environment, the natural processes will take place faster. Therefore, the process of bioremediation of contaminated soils should be not only correct but also controlled.

The soil cleaned and restored from harmful toxicants can be subsequently used to improve urban areas, grow seedlings of various crops on its basis, form lawns and flower beds, improve park areas and other areas of activity.

Materials and methods

When bioremediating soils and biocomposting in piles (stacks) with a height of 1.0–1.8 m, it is necessary to regularly mix the mixtures' components to saturate the mass with oxygen in the air. This process is carried out by special technical means – aerators-mixers, which can additionally be equipped with systems for introducing biological additives and water. However, these machines do not produce sufficiently high-quality stirring of the compacted caked mass, especially at high humidity. They do not always form a pile of the required shape.

The paper aims to increase the efficiency of soil bioremediation by improving the technical means used for the aeration of soil piles.

The research tasks are:

- To develop technical solutions for improving the semi-suspended aerator-mixer of piles;
- To conduct experimental studies and obtain analytical dependencies that allow justifying the rational parameters of the upgraded machine.

Aerators-mixers are widely used for accelerated composting of various types of organic waste. The main structural elements of these machines are (1) load-bearing structures made in the form of arches, (2) agitating mechanisms, (3) support wheels, (4) systems for introducing liquid components, and (5) mechanisms for driving working bodies. The active working body (stirring cylinder) is often equipped with a screw or screw winding of various configurations [1; 2].

To confirm the theoretical prerequisites for improving the mechanisms of the aerator-mixer, substantiate its rational design and technological parameters, and conduct experimental research in the scientific laboratory of the department "Cars, Tractors and Agricultural Machines" of the Velikiye Luki State Agricultural Academy, a laboratory installation was developed.

We found that the following factors have the most significant influence on the process of aeration of the piles: (1) constructive (the number of working blades on the stirring cylinder), (2) operation (the rotation frequency of the stirring cylinder, and the speed of the machine). The influence of these factors on the process of aeration of soil piles was assessed by the density of the mass after its turning.

Based on the recommendations of a number of scientists [3] and the analysis of the technical characteristics of aerator-mixer piles, we applied the cylinder rotation frequency in the range from 300 to 400 min- for the experiment. This parameter was varied by changing the engine speed. The speed control was carried out using a digital magnetic tachometer. The number of working blades on a three meters long agitating cylinder varied in the range from 36 to 60 pieces. The speed of mass supply to the agitation zone during the experiment was changed in the range of 0.15–0.25 km/h by changing the transmission ratio. A digital magnetic tachometer controlled it.

Results

In the North-Western region of Russia, a semi-suspended aerator-mixer of the TG 301 series is widely used for biocomposting. For the possibility of its use in bioremediation of soils and activation of the biodegradation processes of the toxicant, we propose to make changes to the design of the agitating drum of the aerator-mixer equipping it not only with working blades of a new shape but also with a screw winding. This fact allows increasing the contact area with the treated mass and forming a pile of the required shape.

The main components of the designed machine (Fig. 1) are the following:

- Hitch mechanism;
- Container for water and biological products-destructors;
- Hydraulic cylinder for transferring the machine to the working and transport position;
- Stirring cylinder 4 with working blades and screw winding;
- Frame of the machine of the arched type;
- Spraying nozzles placed on the pipes-collectors of distribution systems.

The working knife-shaped blades are welded to the stirring drum in a spiral and the turns of the screw winding.

The developed design of the stirring cylinder provides a large contact area of the working body with the processed material. In the operation process, the knife-shaped blades enter the soil mass, carrying out its engagement, rupture, and shifting. During these manipulations, the clods that have formed are broken.

They are crushed, and the mass becomes looser and saturated with oxygen while a new volumetric soil pile is formed. The nozzles spray biological products and water,contributing to the acceleration of the processes of bio-oxidation of the toxicant.

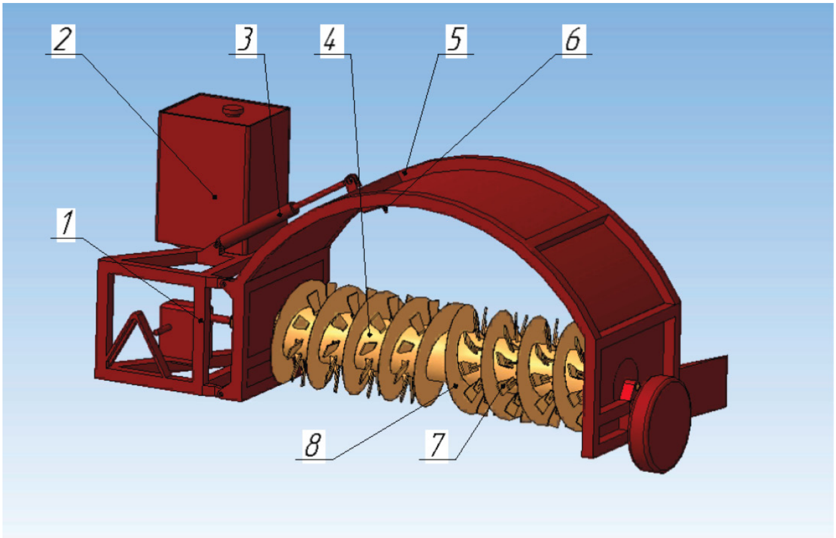

Fig. 1. Structural scheme of the soil aerator-mixer. *Note*: 1 – hitch mechanism; 2 – container; 3 – hydraulic cylinder; 4 – stirring cylinder; 5 – frame; 6 – spraying nozzles; 7 – working blade; 8 – screw winding.

An apron-reflector mounted on the machine frame allows forming a soil pile of the required shape. The design of special clips ensures quick removal of the reflector if it is necessary to replace it and for the convenience of maintenance of mechanisms.

Based on the results of the experimental studies and the statistical analysis carried out using a standard software package, we obtained the following regression equation. It describes the relationship of the studied factors with the output parameter:

$$\rho = 17.8187 - 0.2072 \cdot \omega + 3.18738 \cdot n - 59.375 \cdot V + 0.00023 \cdot \omega \cdot n + \\ + 0.164 \cdot \omega \cdot V + 0.095 \cdot n \cdot V + 0.0002795 \cdot \omega^2 - 0.0234375 \cdot n^2 - 123.5 \cdot V^2, \quad (1)$$

where ρ – the density of the soil pile after its turning, kg/m^3;

ω – stirring cylinder rotation speed, min^{-1};

n– the number of working knife-shaped blades on the cylinder, pcs;

V – the machine movement speed, i.e., the speed of arrival of soil mass to the stirring mechanism, m/min.

The determination coefficient of the presented regression equation has a high value of 0.992. Therefore, we can consider the resulting mathematical model relatively good. It explains 97.85% of the changes in the output parameter ρ. The model is significant since we can see a statistically significant relationship between the variables under consideration.

We studied the joint influence of the factors on the density of the soil mass. Thus, we can observe its decrease with an increase in the rotation frequency of the stirring drum. The lowest density of the soil after its turning was 630 kg/m^3.It corresponds to the cylinder rotation frequency of 350 min^{-1}, the number of working blades of 44 pieces in the range of working speeds from 2.3 to 2.5 m/min.

Discussion

Scientific publications from different countries dealing with topical problems of the stability of natural-anthropogenic systems indicate the need to create optimal conditions for the active course of microbiological processes of toxicant oxidation: (1) creating aerobic conditions, (2) providing available nutrients, (3) maintaining the necessary soil moisture and acidity, (4) temperature, and other parameters [8; 16]. Thus, the soil piles should be aerated and create the necessary moisture in them and introduce nutrients for microorganisms [2].

Many researchers [13; 14; 20] note that providing bioremediation processes with oxygen is the most critical factor in their stable course. When there is a lack of oxygen, the oxidation processes slow down. The same is observed when the ambient temperature decreases, while destructive microorganisms retain their viability even at subzero temperatures. With an increase in temperature in soil piles, the processes of toxicant oxidation are restored [9; 11].

An essential role in the stable course of bioremediation processes is also assigned to moisture in the soil. It is the transport medium through which all the nutrition elements and the pollutant itself enter the cell and remove metabolic products [2; 4].

In their research, Maria Concetta Tomei and Andrew Daugulis note the significant potential of *ex situ* soil bioremediation technology [20]. However, they also point to the fact that there is still a need to improve approaches to their implementation and innovations in their technical support.

At high humidity and a high degree of soil contamination, many researchers [5; 11; 15] recommend forming soil piles with the simultaneous introduction of moisture-retaining materials, such as straw, peat, sawdust, sapropel, organic waste from food and processing industries. In this case, the use of aerators-mixers that perform intensive mixing of various components of soil mixtures, destruction of large soil formations, and saturation of piles with oxygen is an essential component of the qualitative flow of soil bioremediation processes. An important role is also given to technical means that ensure the implementation of technological processes in accordance with the requirements established by the regulations.

Conclusion

The problem of restoring soil fertility and involving purified soils in the production process is among the most essential applied tasks in the field of environmental protection and reproduction of natural bioresources that need to be solved in the shortest possible time. A special place among the well-known approaches to eliminating human-made pollutants is occupied by bioremediation technologies implemented based on the use of special technical means and biological products.

For the high-quality course of the processes of bio-oxidation of toxicants, one should maintain the technological regimes established by the relevant regulations for carrying out work – to mix soil piles, saturating them with air oxygen, moisten the mass and introduce the necessary nutrition elements for microorganisms. At high soil humidity and a significant pollution level, we recommend adding bulk organic fillers (straw, peat, sawdust, and other waste from wood processing enterprises) to the soil piles.

In order to increase the efficiency of bioremediation of soils in piles based on the use of a semi-suspended aerator-mixer, we propose to improve the stirring cylinder of the machine by equipping it with knife-shaped working blades and a screw winding that diverges from the center of the cylinder to the edges. The rational parameters of the improved machine arethe cylinder rotation frequency of 350 min^{-1}, the number of working blades of 44 pieces, and working speed from 2.3 to 2.5 m/min.

References

1. Kokunova I. V., Kotov E. G. K *obosnovaniyu rabochikh organov kompost-nogo aeratora-miksera* [To substantiation of the working attachments of the compost aerator-mixer]. *Materialy Mezhdunarodnoy nauchno-prakticheskoy konferentsii "Nauchno-tekhnicheskiy progress v sel'skokhozyaystvennom proiz-vodstve".* [Proceedings of the International Scientific-Practical Conference "Sci-entific-Technical Progress in Agricultural Production]." Velikiye Luki, 2019, pp. 209-217.

2. Kokunova I. V., Nikandrov Yu. K. Primeneniye aeratora-smesitelya kompostov pri bioremediatsii pochv [The use of a compost aerator-mixer for bioremediation of soils]. *Materialy regional'noy nauchno-prakticheskoy konferentsii «Dostizheniya nauki v oblasti APK* [Proceedings of the regional scientific-practical conference "Achievements of science in the field of agro-industrial complex"]. Velikie Luki, 2020, pp. 39-42.
3. Kotov Ye. G., Kokunova I. V., Ruzh'yev V. A. Eksperimental'nyye issledovaniya aeratora-smesitelya kompostnykh burtov [Experimental studies of the aerator-mixer of compost piles]. *Izvestiya Orenburgskogo Gosudarstvennogo Agrarnogo Universiteta* [Proceedings of the Orenburg State Agrarian University], 2019. vol. 4, no. 78, pp. 127-130.
4. Mironov V. V., Zatsepin I. S. Razrabotka klassifikatsii metodov i tekhnicheskikh sredstv pererabotki otkhodov zhivotnovodstva [Development of classification for methods and technical means to the animal waste processing]. *Zhurnal VNIIMZH* [Journal of VNIIMZH], 2015, no. 4, pp. 119-124.
5. Nikandrov Yu. K. Retsikling otkhodov zhivotnovodstva i ikh ispol'zovaniye v organicheskom zemledelii [Recycling of animal husbandry waste and its use in organic farming]. *Osnovy i Perspektivy Organicheskikh Biotekhnologiy* [Fundamentals and perspectives of organic biotechnologies], 2020, no. 1, pp. 25-28.
6. Polyak Yu. M., Sukharevich V. I. Pochvennyye fermenty i zagryazneniye pochv: biodegradatsiya, bioremediatsiya, bioindikatsiya [Soil enzymes and soil pollution: Biodegradation, bioremediation, bioindication]. *Agrokhimiya* [Agrokhimiya], 2020. no. 3, pp. 83-93.
7. Romanova M. N., Shimova Yu. S. Bioremediatsiya urbanizirovannykh pochv [Bioremediation of urbanized soils]. *Materialy Vserossiyskoy nauchno-prakticheskoy konferentsii «Ekologiya, ratsional'noye prirodopol'zovaniye i okhrana okruzhayushchey sredy* [Proceedings of the All-Russian Scientific-Practical Conference "Ecology, rational nature management, and environmental protection"]. Lesosibirsk, 2020, pp. 124-126.
8. Rudenko Ye. Yu. *Bioremediatsiya neftezagryaznennykh pochv organicheskimi komponentami otkhodov pishchevoy (pivovarennoy) promyshlennosti* [Bioremediation of oil-contaminated soils with organic components of food (brewing) industry waste]: Abstract of the thesis. Doc. Bio. Sciences, 2015, 22 p.
9. Silachi A.Yu., Signalova M.A., Shlokova I.Yu. Bioremediatsiya pochv v promyshlennykh zonakh goroda [Bioremediation of soils in industrial zones of the city]. *Elektronnyy nauchno-metodicheskiy zhurnal Omskogo GAU* [Electronic scientific and methodological journal of the Omsk State Agrarian University], 2018, vol. 2, no. 13, p. 8.

10. Stupin D. Yu. *Zagryazneniye pochvy i tekhnologii yeye vosstanovleniya* [Soil pollution and technologies for its restoration]. St. Petersburg, Lan, 2021, 432 p.
11. Yankevich M. I., Khadeyeva V. V., Murygina V. P. Bioremediatsiya pochv: vchera, segodnya, zavtra [Soil bioremediation: Yesterday, today, tomorrow]. *Biosfera* [Biosfera], 2015, vol. 7, no. 2, pp. 199-208.
12. Buchmann C., Schaumann G. E. The contribution of various organic matter fractions to soil-water interactions and structural stability of an agriculturally cultivated soil. *Journal of Plant Nutrition and Soil Science*, 2018, vol. 181, no. 4, pp. 586-599.
13. Burns R. G., Deforest J. L., Marxsen J., Sinsabaugh R. L., Stromberger M.E., Wallenstein M.D. Soil enzymes in a changing environment: current knowledge and future directions. *Soil Biol. Biochem*., 2013, vol. 58, pp. 216– 234.
14. Lehmann A., Stahr K. Nature and significance of anthropogenic urban soils. *Journal Soils Sediments*, 2007, vol. 7, no. 4, pp. 247-260.
15. Morozov V., Savelyeva L., Nesterova E. Justification of production indicators of organic fertilizer based on sapropel. *2020 International Scientific and Practical Conference Environmental Risks and Safety in Mechanical Engineering*, 2020, 1001 012130. https://doi.org/10.1088/1757-899X/1001/1/012130
16. Polyaka Yu. M., Bakina L. G., Chugunova, M. V., Mayachkinaa N. V., Gerasimova A. O., Bureb V. M. Effect of remediation strategies on the biological activity of oil-contaminated soil – a field study. *International Biodeterioration & Biodegradation*, 2018, vol. 126, pp. 57-68.
17. Rao M. A., Scelza R., Acevedo F., Diez M. C., Gianfreda L. Enzymes as useful tools for environmental purposes. *Chemosphere*, 2014, vol. 107, pp. 145–162.
18. Samarin G. N., Kokunova I. V., Vasilyev A. N., Kudryavtsev A. A. Normov D.A.Optimization of compost production technology. *Intelligent computing and optimization*. ICO 2020 / eds. Vasant P., Zelinka, I., Weber, G.W. Ostrava: Springer, pp. 1319-1327.
19. Steinweg J. M., Dukes J. S., Paul E.A., Wallenstein M. D. Microbial responses to multi-factor climate change: effects on soil enzymes. *Front. Microbiol*, 2013, vol. 4, pp. 1–11.
20. Tomei M. C., Daugulis. A. J. Ex situ bioremediation of contaminated soils: An overview of conventional and innovative technologies. *Critical reviews in Environmental Science and Technology*, 2013. no. 43, pp. 2107-2139.

Список литературы

1. Кокунова И. В., Котов Е. Г. К обоснованию рабочих органов аэратора-смесителя компостов // Материалы международной научно-практической

конференции «Научно-технический прогресс в сельскохозяйственном производстве». ВЛ., 2019. С. 209-217.
2. Кокунова И. В., Никандров Ю. К. Применение аэратора-смесителя компостов при биоремедиации почв // Материалы региональной научно-практической конференции «Достижения науки в области АПК». ВЛ., 2020. С. 39-42.
3. Котов Е. Г., Кокунова И. В., Ружьев В. А. Экспериментальные исследования аэратора-смесителя компостных буртов // Известия оренбургского государственного аграрного университета. 2019. Т.4, № 78. С. 127-130.
4. Миронов В. В., Зацепин И. С. Разработка классификации способов и технических средств переработки отходов животноводства. // Вестник ВНИИМЖ. 2015. № 4. С.119-124.
5. Никандров Ю. К. Рециклинг отходов животноводства и их использование в органическом земледелии // Основы и перспективы органических биотехнологий. 2020. № 1. С. 25-28.
6. Поляк Ю. М., Сухаревич В. И. Почвенные ферменты и загрязнение почв: биодеградация, биоремедиация, биоиндикация // Агрохимия. 2020. № 3. С. 83-93.
7. Романова М. Н., Шимова Ю. С. Биоремедиация урбанизированных почв // Материалы всероссийской научно-практической конференции «Экология, рациональное природопользование и охрана окружающей среды». Лесосибирск, 2020. С. 124-126.
8. Руденко Е. Ю. Биоремедиация нефтезагрязненных почв органическими компонентами отходов пищевой (пивоваренной) промышленности: Автореферат Дис. Док. Био. Наук. 2015. 22 с.
9. Силачи А. Ю., Сигналова М. А., Шлёкова И. Ю. Биоремедиация почв в промышленных зонах города. Электронный научно-методический журнал Омского ГАУ. 2018. Т. 2. № 13. С. 8.
10. Ступин Д. Ю. Загрязнение почв и технологии их восстановления. СПБ., Лань. 2021. 432 с.
11. Янкевич М. И., Хадеева В. В., Мурыгина В. П. Биоремедиация почв: вчера, сегодня, завтра. Биосфера. 2015. Т. 7. № 2. С. 199-208.
12. Buchmann C., Schaumann G. E. The contribution of various organic matter fractions to soil-water interactions and structural stability of an agriculturally cultivated soil // Journal of Plant Nutrition and Soil Science, 2018, vol. 181, no. 4, pp. 586-599.
13. Burns R. G., Deforest J. L., Marxsen J., Sinsabaugh R. L., Stromberger M.E., Wallenstein M.D. Soil enzymes in a changing environment: current knowledge and future directions // Soil Biol. Biochem., 2013, vol. 58, pp. 216– 234.

14. Lehmann A., Stahr K. Nature and significance of anthropogenic urban soils // Journal Soils Sediments, 2007, vol. 7, no. 4, pp. 247-260.
15. Morozov V., Savelyeva L., Nesterova E. Justification of production indicators of organic fertilizer based on sapropel // 2020 International Scientific and Practical Conference Environmental Risks and Safety in Mechanical Engineering, 2020, 1001 012130. https://doi.org/10.1088/1757-899X/1001/1/012130
16. Polyaka Yu. M., Bakina L. G., Chugunova, M. V., Mayachkinaa N. V., Gerasimova A.O., Bureb V.M. Effect of remediation strategies on the biological activity of oil-contaminated soil – a field study // International biodeterioration & biodegradation, 2018, vol. 126, pp. 57-68.
17. Rao M. A., Scelza R., Acevedo F., Diez M. C., Gianfreda L. Enzymes as useful tools for environmental purposes // Chemosphere, 2014, vol. 107. pp. 145–162.
18. Samarin G. N., Kokunova I.V., Vasilyev A. N., Kudryavtsev A.A. Normov D.A.Optimization of compost production technology // Intelligent computing and optimization. ICO 2020 / eds. Vasant P., Zelinka I., Weber G.W. Ostrava: Springer, pp. 1319-1327.
19. Steinweg J. M., Dukes J. S., Paul E. A., Wallenstein M. D. Microbial responses to multi-factor climate change: effects on soil enzymes // Front. Microbiol, 2013, vol. 4. pp. 1–11.
20. Tomei M. C., Daugulis A. J. Ex situ bioremediation of contaminated soils: An overview of conventional and innovative technologies // Critical reviews in environmental science and technology, 2013, no. 43, pp. 2107-2139.

DATA ABOUT THE AUTHORS

Irina V. Kokunova

Velikie Luki State Agricultural Academy
2, Lenin Ave., Velikiye Luki, 182112, Russian Federation
i.kokunova@yandex.ru
OCRID: https://orcid.org/0000-0001-7513-2313

Alexander A. Zhukov

Velikie Luki State Agricultural Academy
2, Lenin Ave., Velikiye Luki, 182112, Russian Federation
zukov5@mail.ru
OCRID: https://orcid.org/0000-0002-9495-1135

Tatyana E. Fyodorova-Semyonova

Velikie Luki State Agricultural Academy
2, Lenin Ave., Velikiye Luki, 182112, Russian Federation

fste@vgsa.ru
OCRID: https://orcid.org/0000-0002-4273-3486

ДАННЫЕ ОБ АВТОРАХ

Кокунова Ирина В.
Великолукская государственная сельскохозяйственная академия
пр. Ленина, 2, г. Великие Луки, 182112, Российская Федерация
i.kokunova@yandex.ru

Жуков Александр А.
Великолукская государственная сельскохозяйственная академия
пр. Ленина, 2, г. Великие Луки, 182112, Российская Федерация
zukov5@mail.ru

Федорова-Семенова Татьяна Е.
Великолукская государственная сельскохозяйственная академия
пр. Ленина, 2, г. Великие Луки, 182112, Российская Федерация
fste@vgsa.ru

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