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ASSESSMENT OF THE IMPACT OF OIL PRODUCTS ON THE DEVELOPMENT OF AGRICULTURAL PLANTS

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The study focuses on the pressing environmental challenge of oil pollution and its detrimental effects on agroecosystems, which play a pivotal role in global food security. With the growing demands of modern sustainable development, industrial and transportation systems are faced with the dual challenge of achieving economic progress while minimizing ecological harm. Among the most significant concerns is the contamination caused by petroleum products, which profoundly affects soil quality, plant health, and overall ecosystem stability. The article explores the toxic mechanisms of hydrocarbons on plant development, particularly their impacts on seed germination, root elongation, and photosynthetic processes, which are essential for growth and productivity. It has been found that even low concentrations of oil products (1–3.0 mg/kg) have a toxic effect on seed germination, root development, and physiological processes such as photosynthesis. It was found that the acidity of the soil varies depending on the degree of oil contamination. In sample № 1, the pH = 6 indicates a rather acidic and toxic soil with iron, aluminum and manganese, which limits the yield to 50%. In sample № 2,

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the pH = 6.4 indicates satisfactory soil acidity. Laboratory tests confirm that natural decomposition and leaching of oil products occurred in the contaminated soil within 6 months, indicating that the soil has begun to cleanse itself through natural mechanisms. By addressing the intersection of environmental sustainability, industrial activity, and agricultural productivity, this research offers valuable insights for agricultural practitioners. The scientific novelty of the study lies in a comprehensive analysis of the impact of petroleum products on the growth and development of agricultural plants, taking into account both the initial and long-term effects. The mechanisms of toxic effects of hydrocarbons on plant physiological processes are studied in detail. Particular attention is paid to the identification of pollution-resistant plant species that can serve as bioindicators or be used for phytoremediation of contaminated areas.

Key words: *oil products, sustainable development, environment, soil pollution, agroecosystems, agricultural plants.*

ОЦІНКА ВПЛИВУ НАФТОПРОДУКТІВ НА РОЗВИТОК СІЛЬСЬКОГОСПОДАРСЬКИХ РОСЛИН

Т. О. Бондар, А. С. Босюк, Д. І. Нечипоренко, В. Є. Ліфер, І. В. Мельник

Дослідження зосереджено на нагальній екологічній проблемі забруднення нафтопродуктами та її негативному впливі на агроекосистеми, які відіграють ключову роль у глобальній продовольчій безпеці. З огляду на зростаючі вимоги сучасного сталого розвитку промислові та транспортні системи стикаються з подвійним викликом: досягнення економічного прогресу за мінімізації екологічної шкоди. Серед найбільш значущих проблем – забруднення, спричинене нафтопродуктами, яке глибоко впливає на якість ґрунту, здоров’я рослин і загальну стабільність екосистеми. У статті досліджуються токсичні механізми впливу вуглеводнів на розвиток рослин, зокрема їхній вплив на проростання насіння, довжину коренів і фотосинтетичні процеси, які є важливими для росту та продуктивності. З’ясовано, що навіть низькі концентрації нафтопродуктів (1–3,0 мг/кг) спричиняють токсичний вплив на проростання насіння, розвиток кореневої системи та фізіологічні процеси, зокрема фотосинтез. Встановлено, що кислотність ґрунту змінюється залежно від ступеня забруднення нафтопродуктами. У зразку № 1 кислотність pH = 6 свідчить про досить кислий і токсичний ґрунт із вмістом заліза, алюмінію та марганцю, що обмежує врожайність до 50%. У зразку № 2 pH = 6,4 вказує на задовільну кислотність ґрунту. Лабораторні дослідження підтверджують, що протягом 6 місяців у забрудненому ґрунті відбувалося природне розкладання та вимивання нафтопродуктів, що свідчить про початок процесу самоочищення ґрунту через природні механізми. Вивчаючи взаємозв’язок між екологічною стійкістю, промисловою діяльністю та продуктивністю сільського господарства, це дослідження пропонує цінну інформацію для практиків сільського господарства. Наукова новизна дослідження полягає у комплексному аналізі впливу нафтопродуктів на ріст і розвиток сільськогосподарських рослин з урахуванням як початкових, так і віддалених наслідків. Детально вивчено механізми токсичної дії вуглеводнів на фізіологічні процеси рослин. Особливу увагу приділено виявленню стійких до забруднення видів рослин, які можуть слугувати біоіндикаторами або використовуватися для фіторемедіації забруднених територій.

Ключові слова: *нафтопродукти, сталий розвиток, довкілля, забруднення ґрунтів, агроекосистеми, сільськогосподарські рослини.*

Introduction

The relevance of the topic of studying the phytotoxic effect of oil products on agricultural plants has increased significantly due to the war in Ukraine. Due to military operations, there is massive soil pollution with oil products as a result of damage to infrastructure, military equipment and fuel depots, which creates an additional burden on the agricultural sector and threatens food security. Toxic contamination of soil and water resources negatively affects land fertility, biodiversity, and the quality of the products grown (Bondar et al., 2024b). Toxic oil pollution can cause phytotoxic effects in agricultural crops, which are manifested by slower seed germination, stunted growth, developmental disorders, and even plant death. This leads to the formation of secondary plant communities, which reduces the productivity of agricultural land. In turn, such changes have a negative impact on food security and economic stability in the region (Bondar & Vedenina, 2024a).

The study aims to evaluate the phytotoxic effects of oil products on agricultural plants using modern research methods, including phytotesting and laboratory analysis of the physical and chemical properties of contaminated soils. The research focuses on analyzing the impact of oil contamination on soil properties, plant growth, and development, identifying methods for assessing phytotoxicity, and determining the resilience or sensitivity of various crops to such contamination. The study also examines soil remediation potential and highlights the importance of addressing oil pollution to protect agricultural ecosystems.

Physicochemical analysis allows us to determine the concentrations of major pollutants and to develop maps of land degradation and pollution. Bacterial decomposition of oil causes an increase in pH by 26%. Hydraulic permeability decreases by 46–67%, which is caused by blocking of micropores by oily products. A correlation between soil pH and soil nitrogen has been established: a higher pH value corresponds to a higher level of nitrogen in the contaminated soil (Essien & John, 2011).

The contamination of soil by petroleum-derived substances results in far-reaching physical, chemical, and biological changes that are most clearly visible in the health status of plants (Wyszkowski & Ziółkowska, 2008). Very often the contaminants contribute to alterations in the content of macro- and microelements in plant organs (Wyszkowski & Ziółkowska, 2009), and also modify the content of heavy metals. Heavy metals (trace elements) play a significant role in metabolic processes in all living organisms. Some of them are essential for the normal growth and development of plants (copper, cobalt, nickel, zinc, chromium, and manganese) because they take part in many enzymatic reactions. However, among trace elements there are heavy metals such as cadmium, lead, and mercury, which may be toxic to cultivated plants even in low concentrations (Nagajyoti et al., 2010).

An analysis of key studies and publications shows that the environmental consequences of oil pollution depend on three groups of factors: pollution parameters, soil properties, and environmental characteristics (Baek et al., 2004; Brandão et al., 2011; Cruz et al., 2013). The issue of scientific research on how man-made impacts and chemicals affect agrophytocenoses, in particular, the interaction between soil and plants, remains relevant (Dybzinski et al., 2008; Taranenko et al., 2019).

Materials and methods

The control soil was used, which did not contain oil products and whose physical and chemical characteristics are similar to those of the experimental site. Two types of soil samples were used in the study: oil-contaminated and control. At the first stage of the study of the phytotoxic effect of oil products on agricultural plants, various species of monocotyledonous and dicotyledonous plants were selected: sweet corn (Dulcis frumentum), nutmeg pumpkin (Nutmeg cucurbita), asparagus beans (Vicia faba L.), Red Coral lettuce (Lactuca sativa L. var. Longifolia), and Senator lettuce (Lactuca sativa var. Foliosa). The initial process of the experimental study (Fig. 1). At the same stage, contaminated soil was prepared for the experiment, which was taken at the site of the oil spill in Kharkiv after a drone strike. The destruction of industrial facilities and infrastructure caused by shelling leads to fires, which become an additional source of soil and water pollution, worsening the environmental situation in the region (Mandryk & Lukynchuk, 2023).

Fig. 1. Control soil and agricultural plants for the experimental test

The phytotesting method was used to conduct this study. It should be noted that the phytotesting method is a type of biotesting to determine the phytotoxic effect on plants and to determine soil toxicity. It is based on the position that soils can be considered an integral indicator of soil ecosystem pollution. The process of phytotesting to assess the toxic effect on plants included several stages. The first stage was the selection and preparation of contaminated and control soil samples, and the selection of plants for testing.

The next stage of phytotesting was sowing and growing plants in contaminated and controlled soil. Agricultural plants were placed in controlled conditions (temperature, humidity, lighting) that are optimal for the growth of selected plant species. After that, we measured plant growth indicators such as root length, stem height, and number of leaves. The research process was recorded using photography to visually assess (Fig. 2) and document the condition of the plants.

Each type was studied in three parallel replications to increase the reliability of the results. The experimental and control samples were studied under identical conditions (temperature, humidity, lighting), which excludes the influence of additional factors. The study was carried out in accordance with the standards governing the study of soils and petroleum product toxicity.

The data were processed using statistical methods to determine the differences between control and experimental samples. The average values of biometric parameters for control and contaminated samples were compared. Based on the data obtained, conclusions were drawn about the level of soil phytotoxicity. Thus, the phytotesting method made it possible to determine the impact of toxic substances on plants and assess potential risks to the ecosystem. Data for each parameter were calculated as the arithmetic mean of three replications. The tables with the results of the study (Table 1 and Table 2) show statistical indicators for each parameter. MS Excel software was used for data processing.

For each plant species, three independent replications were conducted to measure germination parameters root length (cm), and shoot length (cm). Each replication included 10 seeds planted separately on control and contaminated soils. At the end of the experimental period, the above parameters were measured for each replication. The average values were calculated as the arithmetic mean of three replications, and the standard deviation was calculated to assess the variability of the data. The tables summarize the average results for each plant species, which allows us to assess the impact of soil pollution on their growth and development.

Results

The study of soil phytotoxicity to plants was conducted using the phytotesting method. This method is based on the reaction of test cultures to the presence of pollutants in the soil. The method allows to identify the toxic effect of oil products on the development of test crops. During the experiment, germination, shoot and root length were measured. Seed development and germination were evaluated according to the standard methods (DSTU ISO 11269-1:2004, DSTU ISO 1269-2:2002).

On day 35, full phytotesting indicators were obtained – germination, shoot and root length for selected agricultural plants planted in contaminated and control soil. Thus, the data obtained are presented in Table 1 and in Table 2. Tables present the average data for each parameter obtained in the study. Each indicator was calculated as the arithmetic mean of three replications.

Further, to determine the phytotoxic effect of the impact of oil products in the soil on the

Fig. 2. Germination of asparagus beans (Vicia faba L.) and nutmeg (Nutmeg cucurbita)

Table 1

Averages of test reaction indicators for agricultural plants (control soil)

Plant	Sprouting, units	L of the root, cm	L of the shoot, cm
Senator lettuce	37	4	9
Lettuce "Red coral"	42	5	7
Butternut squash (Nutmeg cucurbita)	9	10	23
Sweet corn (Dulcis frumentum)	8	11	23
Asparagus bean (Vicia faba L.)	12	11	22

Table 2

Averages of test reaction indicators for agricultural plants (polluted soil)

Plant	Sprouting, units	L of the root, cm	L of the shoot, cm
Senator lettuce	15	2,5	7
Lettuce "Red coral"	0	-	-
Butternut squash (Nutmeg cucurbita)	4	9	15
Sweet corn (Dulcis frumentum)	3	9	17
Asparagus bean (Vicia faba L.)	7	7	19

germination of agricultural plants by phytotesting in percentage equivalent (%), we use the data from Tables 2 and 3 and the following formulas:

$$PE=\frac{L_0-L_1}{L_0}\cdot 100, \quad (1)$$

where L_0 is the length of the root (shoot) in the control, cm;
L_1 is the length of the root (shoot) in the contaminated one, cm.

$$PE=\frac{B_0-B_1}{B_0}\cdot 100, \quad (2)$$

where B_0 – sprouting in the control soil, units;
B_1 – sprouting in the contaminated soil, units.

The results of calculations of the phytotoxic effect on agricultural plants using the above formulas are shown in Table 3.

According to visual observations and calculations to determine the phytotoxic effect on agricultural plants, we have the following results (Fig. 3):

1. Senator lettuce has a phytotoxic effect on germination of 59,4% and a phytotoxic effect on root length of 59,4%. This indicates a level of above average soil toxicity.
2. The Red Coral lettuce had a 100% phytotoxic effect on germination and a 100% phytotoxic effect on root length, indicating the maximum toxicity effect on the plant. The lettuce germinated but later died in the contaminated soil. However, it germinated and developed in the control soil.
3. Nutmeg cucurbita has a phytotoxic effect on germination of 55,5% – the level of toxicity is higher than average, the effect of phytotoxic effect on root length is 80,0%. Thus, the phytotoxic effect on the plant is high.
4. Sweet corn (Dulcis frumentum) – has a phytotoxic effect on germination of 62,5% and the effect of phytotoxic effect on root length

Table 3

Results of determining the phytotoxic effect on agricultural plants (contaminated soil)

Plant	Influence of phytotoxic effect on sprouting, %	Influence of phytotoxic effect on root length, %	Influence of phytotoxic effect on shoot length, %
Senator lettuce	59,4	58,5	68,7
Lettuce "Red coral"	100	100	100
Butternut squash (Nutmeg cucurbita)	55,5	80,0	42,2
Sweet corn (Dulcis frumentum)	62,5	70,8	50,9
Asparagus bean (Vicia faba L.)	41,6	52,6	64,3

reaches 70,8% – this is also a high level of toxicity.

5. Asparagus bean (Vicia faba L.) – has a phytotoxic effect on germination of 41,6% and the effect of phytotoxic effect on root length reaches 52,6%, which indicates an above-average level of toxicity.

An important property of the environment is its ability to self-purify, which is a key factor in the processes of natural ecosystem restoration. In our study, we used the method of microscopy of the surface layer of the water extracted soil to assess the ability of soils to self-purify from oil contamination. For this purpose, in August 2024, soil samples were re-collected from the site with an oil leak in Kharkiv. A previous sample of contaminated soil was taken at the same site in April 2024 to compare changes in soil condition between the sample collections.

The microscopy of the surface layer of the water extract of the soil revealed a significant amount of oil products in sample № 1: oil droplets and hydrocarbon (carbon) particles (Fig. 4a). The soil has a characteristic odor of petroleum products. In addition, during the study, when the soil was placed in a laboratory bowl and filled with distilled water, a clear dark-colored lubricating film formed over time, covering the entire surface of the bowl (a visual representation of the study is shown in Fig. 4b). This phenomenon also indicates a high content of oil products in sample № 1, which is confirmed by the visual images (Fig. 4a).

Instead, the microscopy of the surface layer of the water extract of the soil in sample № 2 revealed a smaller number of oil droplets and hydrocarbon particles (carbon) (Fig. 5). The size of these particles has decreased, and small clay particles were also observed. However, the soil still has a characteristic odor of petroleum products, and the color has remained unchanged, indicating that the soil has been partially, but not completely, cleaned of contaminants.

Having obtained both results of microscopy of the surface layer of the water extract of the soil, the acidity (pH) of the soil in samples № 1 and № 2 was additionally determined in the laboratory. The data obtained are shown in Table 4.

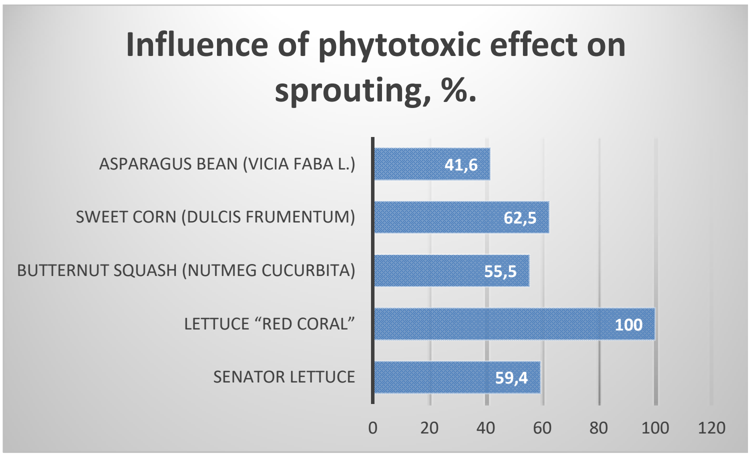

Fig. 3. Results of visual observations and calculations to determine the phytotoxic effect on agricultural plants

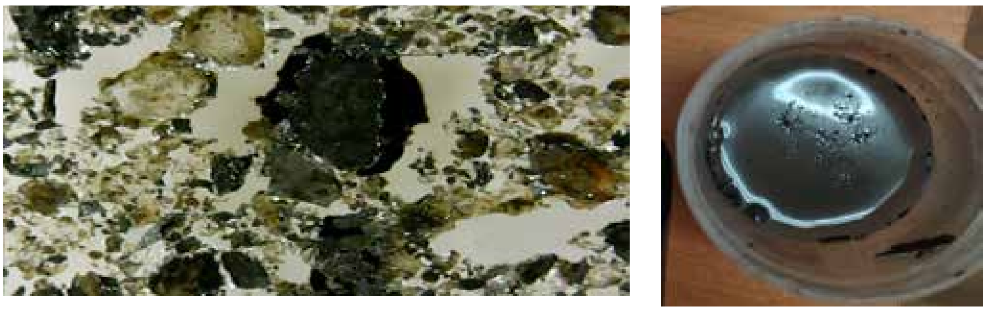

Fig. 4. Investigation of contaminated soil:
a – microscopy of the surface layer of the water extract of contaminated soil. Sample № 1; b – a bowl with a mixture of soil sample № 1 and distilled water

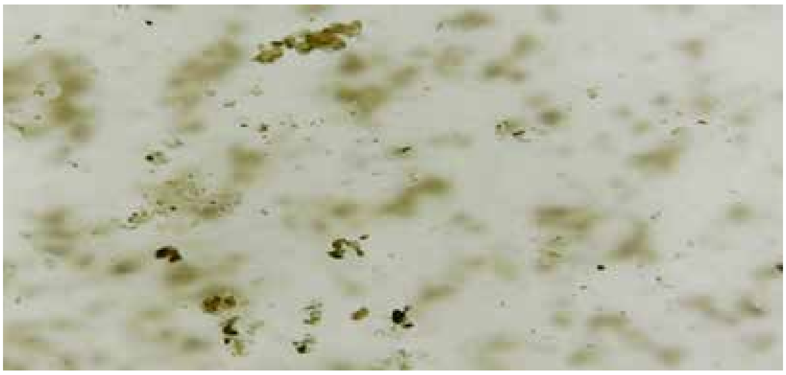

Fig. 5. Microscopy of the surface layer of the water extract of contaminated soil. Sample № 2

Table 4

Determination of soil pH by the potentiometric method of water extraction

Sample number (№)	Water extraction solution	pH
№ 1 (April 2024)	pH of the water extract (20 g of soil + 100 ml of distilled water)	pH = 6
№ 2 (August 2024)	pH of the water extract (20 g of soil + 100 ml f distilled water)	pH = 6,4

Based on the results of the study (Table 4), sample № 1 has an acidity of pH = 6. This indicates a rather acidic and toxic soil and the presence of iron, aluminum, and manganese in it. It is believed that the composition of such soil gives a yield of 50%. In sample № 2, pH = 6.4, the soil acidity is considered satisfactory. Thus, based on the results of both laboratory tests, it can be stated that natural decomposition and leaching of oil products from the contaminated soil occurred over 6 months. This indicates a certain process of self-cleaning of the soil through natural mechanisms of reducing the concentration of oil products, although complete cleanup has not yet been achieved.

Discussion

When oil products enter the geological environment in a liquid state, they migrate as a non-miscible substance with water, creating a distinct phase within the soil. In cases where the quantity of oil products does not exceed the soil's retention capacity, they remain within the aeration zone, and further migration can occur through dissolution in infiltration water. This process is influenced by factors such as soil permeability, the viscosity of the oil products, and the volume of precipitation that facilitates water infiltration. As the oil dissolves into the infiltrating water, it may spread horizontally through the soil profile, potentially affecting a larger area.

However, if the inflow of oil products surpasses the soil's retention capacity, they are able to penetrate deeper into the ground, reaching the groundwater aquifer. This results in the formation of an oil product lens on the surface of the groundwater. The presence of such a lens can lead to significant contamination of the water source, as oil products are not easily biodegraded and can persist for extended periods. The thickness of this lens and its potential spread depend on several factors, including the type of oil product, the depth and permeability of the aquifer, and the rate of groundwater flow.

The migration of oil products through the soil and into groundwater is a significant environmental concern, as it can lead to the contamination of drinking water supplies, disrupt local ecosystems, and create long-term environmental challenges. Moreover, the interaction between oil products and soil microorganisms can influence the rate of biodegradation and, consequently, the persistence of contaminants in the environment.

Conclusions

The article examines the effects of petroleum products on soil, revealing that oil contamination disrupts the soil's air regime and alters its water properties. Methods for studying phytotoxic effects are described, including phytotesting to assess soil toxicity, along with laboratory techniques such as microscopy of the surface layer of water extracts from contaminated soil and pH measurement of soil using the potentiometric method.

The study uncovered the phytotoxic impact of petroleum products on agricultural plants, showing that all plants in contaminated soil experienced medium to high levels of toxicity, which adversely affected their development. Lettuce "Red Coral" and sweet corn (Dulcis frumentum) were found to be the least resistant to the toxic effects, while asparagus beans (Vicia faba L.) exhibited the highest tolerance. Plants grown in control soil demonstrated superior germination rates and overall development.

Microscopy of the water extract's surface layer from contaminated soil samples (collected in April and August 2024) and pH-metry of soil extracts were performed. Laboratory results indicated that, initially, the soil was acidic and toxic, containing heavy metals and oils. These conditions suggest a potential crop yield reduction to no more than 50%.

Bibliography

Бондар Т.О., Веденіна М. Екологічні проблеми під час війни в Україні: вплив нафтопродуктів на сільськогосподарські рослини. *Modern information technologies in education and science* : збірник матеріалів. The XXX International Scientific and Practical Conference. Prague, 2024. С. 7–9.

Бондар Т.О., Веденіна М.В., Шестопалов О.В. Фітотоксичний ефект нафтопродуктів на сільськогосподарські рослини: експериментальне дослідження. *Research of young scientists: from idea generation to project implementation :* збірник матеріалів. Abstracts of IX International Scientific and Practical Conference. Lyon, 2024. С. 11–14.

Колєснікова Л.А, Галицька М.А., Піщаленко М.А., Бараболя О.В., Чубук Д.І., Литвишко О.А. Реакція сільськогосподарських рослин на забруднення ґрунту нафтою. *Вісник Полтавської державної аграрної академії.* 2019. № 4. С. 100–107. https://doi.org/10.31210/visnyk2019.04.12

Мандрик О.М., Лукинчук О.І. Удосконалення способу очищення ґрунту забрудненого нафтопродуктами. *Збірник наукових праць Уманського національного університету садівництва.* 2023. № 1 (103). С. 273–281. https://doi.org/10.32782/2415-8240-2023-103-1-273-281.

ДСТУ ISO 11269-1:2004 Якість ґрунту. Визначення дії забрудників на флору ґрунту. Частина 1. Метод визначання інгібіторної дії на ріст коренів. [Чинний від 2004-04-30]. Вид. офіц. Київ, 2005. 23 с. (Інформація та документація).

ДСТУ ISO 11269-2:2002 Якість ґрунту. Визначання дії забруднювачів на флору ґрунту. Частина 2. Вплив хімічних речовин на проростання та ріст вищих рослин. [Чинний від 2002-07-12]. Вид. офіц. Київ, 2004. 22 с. (Інформація та документація).

Baek K.H., Kim H.S., Oh H.M., Yoon B.D., Kim J., Lee, I.S. Effects of Crude Oil, Oil Components, and Bioremediation on Plant Growth. *Journal of Environmental Science and Health.* 2004. Part A. Vol. 39. № 9. P. 2465–2472. https://doi.org/10.1081/ese-200026309.

Brandão M., Milà i Canals L., Clift, R. Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. *Biomass and Bioenergy.* 2011. Vol. 35. № 6. P. 2323–2336. https://doi.org/10.1016/j.biombioe.2009.10.019.

Cruz J.M., Lopes P.R.M., Montagnolli R.N., Tamada I.S., Silva N.M.M.G., Bidoia E.D. Phytotoxicity of Soil Contaminated with Petroleum Derivatives and Biodiesel. *Ecotoxicology and Environmental Contamination.* 2013. Vol. 8. № 1. P. 49–54. https://doi.org/10.5132/eec.2013.01.007.

Dybzinski R., Fargione J.E., Zak D.R., Fornara D., Tilman D. Soil fertility increases with plant species diversity in a long-term biodiversity experiment. *Oecologia.* 2008. Vol. 158. № 1. P. 85–93. https://doi.org/10.1007/s00442-008-1123-x.

Essien O., John I. Impact of Crude-Oil Spillage Pollution and Chemical Remediation on Agricultural Soil Properties and Crop Growth. *Journal of Applied Sciences and Environmental Management.* 2011. Vol. 14. № 4. P. 147–154. https://doi.org/10.4314/jasem.v14i4.63304.

Nagajyoti P.C., Lee K.D., Sreekanth T.V.M. Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters.* 2010. Vol. 8. № 3. P. 199–216. https://doi.org/10.1007/s10311-010-0297-8.

Taranenko A., Kulyk M., Galytska M., Taranenko S. Effect of cultivation technology on switchgrass (Panicum virgatum L.) productivity in marginal lands in Ukraine. *Acta Agrobotanica.* 2019. Vol. 72. № 3. P. 1786–1801. https://doi.org/10.5586/aa.1786.

Wyszkowski M., Ziółkowska A. Effect of petrol and diesel oil on content of organic carbon and mineral components in soil. *American-Eurasian Journal of Sustainable Agriculture.* 2008. Vol. 2. № 1. P. 54–60.

Wyszkowski M., Ziółkowska A. Effect of compost, bentonite and calcium oxide on content of some macroelements in plants from soil contaminated by petrol and diesel oil. *Journal of Elementology*. 2009. Vol. 2. P. 405–418. https://doi.org/10.5601/jelem.2009.14.2.21.

References

Bondar, T.O., & Vedenina, M.V. (2024a). Ekologichni problemy pid chas viyny v Ukrayini: vplyv naftoproduktiv na silskohospodarski roslyny [Environmental problems during the war in Ukraine: the impact of oil products on agricultural plants]. *Modern information technologies in education and science*: *The XXX International Scientific and Practical Conference*. Czech Republic, 7–9 [in Ukrainian].

Bondar, T.O., Vedenina, M.V., & Shestopalov, O.V. (2024b). Fitotoksychnyi efekt naftoproduktiv na silskohospodarski roslyny: eksperymentalne doslidzhennia [Phytotoxic effect of oil products on agricultural plants: an experimental study]. *Research of young scientists: from idea generation to project implementation: Abstracts of IX International Scientific and Practical Conference*. France, 11–14 [in Ukrainian].

Kolesnikova, L.A., Galytska, M.A., Pischalenko, M.A., Barabolia, O.V., Chubuk, D.I., & Litvishko, O.A. (2019). Reaktsiya silskogospodarskykh roslyn na zabpyдnennya grunty naftoyu [Reaction of crops on soil pollution with oil]. *Visnyk Poltavskoi derzhavnoi ahrarnoi akademii [Bulletin of the Poltava State Agrarian Academy]*, 4, 100–107. https://doi.org/10.31210/visnyk2019.04.12 [in Ukrainian].

Mandryk, O.M., & Lukynchuk, O.I. (2023). Udoskonalennya sposobu ochyshchennya grunty zabpydnenogo naftoproduktamy. [Improving method of cleaning soil contaminated by petroleum products]. *Zbirnyk naukovykh prats Umanskoho natsionalnoho universytetu sadivnytstva. [Collected Works of Uman National University of Horticulture]*, 1 (103), 273–281. https://doi.org/10.32782/2415-8240-2023-103-1-273-281 [in Ukrainian].

DSTU ISO 11269-1:2004 Yakist hruntu. Vyznachennya diyi zabpyдnykiv na floru hruntu. Chastyna 1. Metod vyznachannya inhibitornoyi diyi na rist koreniv. [Chynnyy vid 2004-04-30]. Vud. ofits. Kyiv, 2005. 23 s. (Informatsiya ta dokumentatsiya) [DSTU ISO 11269-1:2004 Soil quality. Determination of the effect of pollutants on soil flora. Part 1: Method for determination of inhibitory effect on root growth. [Valid from 2004-04-30]. Published by the official. Kyiv, 2005. 23 p. (Information and documentation)] [in Ukrainian].

DSTU ISO 11269-2:2002 Yakist hruntu. Vyznachennya diyi zabpyдnyuchiv na floru hruntu. Chastyna 2. Vplyv khimichnykh rechovyn na prorostannya ta rist vyshchykh roslin. [Chynnyy vid 2002-07-12] Vud. ofits. Kyiv, 2004. 22 s. (Informatsiya ta dokumentatsiya) [DSTU ISO 11269-2:2002 Soil quality. Determination of the effect of pollutants on soil flora. Part 2. Effect of chemicals on germination and growth of higher plants. [Valid from 2002-07-12]. Published by the official. Kyiv, 2004. 22 p. (Information and documentation)] [in Ukrainian].

Baek, K.-H., Kim, H.-S., Oh, H.-M., Yoon, B.-D., Kim, J., & Lee, I.-S. (2004). Effects of Crude Oil, Oil Components, and Bioremediation on Plant Growth. *Journal of Environmental Science and Health*, Part A, 39 (9), 2465–2472. https://doi.org/10.1081/ese-200026309 [in English].

Brandão, M., Milà i Canals, L., & Clift, R. (2011). Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. *Biomass and Bioenergy*, 35 (6), 2323–2336. https://doi.org/10.1016/j.biombioe.2009.10.019 [in English].

Cruz, J.M., Lopes, P.R.M., Montagnolli, R.N., Tamada, I.S., Silva, N.M.M. G., & Bidoia, E.D. (2013). Phytotoxicity of Soil Contaminated with Petroleum Derivatives and Biodiesel. *Ecotoxicology and Environmental Contamination*, 8 (1), 49–54. https://doi.org/10.5132/eec.2013.01.007 [in English].

Dybzinski, R., Fargione, J.E., Zak, D.R., Fornara, D., & Tilman, D. (2008). Soil fertility increases with plant species diversity in a long-term biodiversity experiment. *Oecologia*, 158 (1), 85–93. https://doi.org/10.1007/s00442-008-1123-x [in English].

Essien, O., & John, I. (2011). Impact of Crude-Oil Spillage Pollution and Chemical Remediation on Agricultural Soil Properties and Crop Growth. *Journal of Applied Sciences and Environmental Management*, 14 (4), 147–154. https://doi.org/10.4314/jasem.v14i4.63304 [in English].

Nagajyoti, P.C., Lee, K.D., & Sreekanth, T.V.M. (2010). Heavy metals, occurrence and toxicity for plants: a review. Environmental Chemistry Letters, 8 (3), 199–216. https://doi.org/10.1007/s10311-010-0297-8 [in English].

Taranenko, A., Kulyk, M., Galytska, M., & Taranenko, S. (2019). Effect of cultivation technology on switchgrass (Panicum virgatum L.) productivity in marginal lands in Ukraine. *Acta Agrobotanica*, 72 (3), 1786–1801. https://doi.org/10.5586/aa.1786 [in English].

Wyszkowski, M., & Ziółkowska, A. (2008). Effect of petrol and diesel oil on content of organic carbon and mineral components in soil. *American-Eurasian Journal of Sustainable Agriculture*, 2 (1), 54–60 [in English].

Wyszkowski, M., & Ziółkowska, A. (2009). Effect of compost, bentonite and calcium oxide on content of some macroelements in plants from soil contaminated by petrol and diesel oil. *Journal of Elementology*, 14 (2), 405–418. https://doi.org/10.5601/jelem.2009.14.2.21 [in English].

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