

MECHANICAL AND PHYSICAL DEGRADATION OF ARABLE SOILS AS A RESULT OF MILITARY OPERATIONS IN UKRAINE

Plisko I.¹, Romanchuk K.², Krylach S.³

National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovskyi», 4 Chaikovska Str., Kharkiv, 61024, Ukraine;

e-mail: ¹ irinachujan@gmail.com, ² katerina_uvarenko@ukr.net, ³ svetlana.krylach@gmail.com;

ORCID: ¹ 0000-0001-8111-7662; ² 0000-0002-1150-3135; ³ 0000-0002-3347-6561

Goal. Based on the study of the impact of military actions on the main agrophysical parameters of soils, to identify the peculiarities of the manifestation of their mechanical and physical degradation, and to propose effective anti-degradation measures that will make it possible to restore the fertility of damaged soils. **Methods.** Information-analytical, field, laboratory-analytical, and mathematical-statistical methods were used. **Results.** Analysis of literary sources confirmed the negative impact of military operations on soils and soil cover. The redistribution of the fractions of typical heavy loamy chernozem, which was affected by the explosions of projectiles of different calibers (120, 155, and 330 mm), was established, namely an increase in the content of silt fractions (particles smaller than 0.001 mm), and physical clay (the sum of particles smaller than 0.01 mm) compared to the control option (undamaged area). An increase in the density of the soil structure by 0.39 g/cm³ compared to the control variant was noted in the upper 10-centimeter layer of the soil in the places of paths formed as a result of the movement of military equipment. Measures to overcome the consequences of mechanical and physical degradation are proposed, the main of which are the use of various methods of soil cultivation and agrotechnical melioration, aimed at increasing the strength of the root layer and improving the agrophysical properties of arable land. **Conclusions.** The expediency of further in-depth studies of the impact of military actions on arable soils to find ways to restore their fertility in the conditions of martial law and in the post-war period to obtain stable harvests of

crops is proven. Key words: agrophysical parameters, military actions, arable soils, anti-degradation measures.

DOI: <https://doi.org/10.31073/agrovisnyk202310-01>

Modern scientific research indicate that in recent decades more than 30% of land resources in Europe (including the lands of Ukraine) have already shown signs of degradation [1–7]. In connection with the full-scale war that Russia started against Ukraine on February 24, 2022 and which, unfortunately, continues today, the issues of studying the degradation processes caused by the impact of military actions on the environment in general and on the soil cover in particular are extremely relevant. According to estimates of the Food and Agricultural Organization of the United Nations, during the war in Ukraine, the amount of significantly degraded agricultural land increased by 13%, at the same time, a significant percentage of land is under threat of degradation [8]. Due to the deterioration of the quality of land, a decrease in agricultural productivity, and a decrease in the country's ability to export agricultural products, the war poses a threat to the food security of the entire world [9, 10].

The destruction associated with modern warfare is particularly catastrophic because of its scale and duration. The use of the entire available arsenal of weapons systems, the latest military equipment and ammunition leads to radical changes in the landscape, limiting its ability to recover to its original state, and to a global decrease in the productivity of arable soils [11].

In general, mechanical damage to soils is associated with deformation of the soil cover during the movement of wheeled and tracked military equipment, direct movement of troops, bombing, demining of territories, and construction of defense infrastructure. The movement of a large amount of soil mass occurs through the construction of underground shelters and tunnels. Mining of territories and approaches to positions also leads to the destruction, mainly of the upper fertile layer of the soil, which causes the development of erosion processes [12, 13]. As a result of shelling, the bursting of shells and mines, the area (fields) is littered with

ash and metal fragments that fly up to a distance of 120 m, which is the reason for the limited suitability of land plots for agricultural use [14, 15].

Physical damage to soils as a result of the use of various weapon systems and heavy military equipment primarily causes a change in their physical properties. The main manifestations of physical disturbance are overcompaction and destructuring of the soil. The vibrational impact is also singled out — impulses from ammunition explosions and from firing from various weapon systems. The vibration transmitted in the soil can cause its compaction, squeezing of water, subsidence of the surface, formation of cavities and changes in the microrelief [16].

The results of numerous studies by foreign scientists indicate that the movement of military tracked vehicles also leads to soil compaction [17, 18]. Even the movement of foot columns during military exercises can increase the soil bulk density (by 32% compared to the control area), reduce the rate of water infiltration (by almost 83%), reduce above-ground biomass, and increase the risk of wind and water erosion [19].

Research conducted at a military range to study the impact on the soil of the passage of various armored combat vehicles showed that the intensive use of the Leopard 1A5BR during the year caused the degradation of roads, fields and drains. The greatest compaction (from 1.2 to 1.5 g/cm³) occurred in the surface layer of the soil at a depth of 0–6 cm during the 3-time passage of columns of military equipment [20]. Similar data were obtained for the Abrams M1A1 tracked tank, which even in one pass can cause surface (at a depth of 0 to 15 cm) soil compaction up to 1.4 g/cm³, especially when it comes to soil with a light granulometric composition. The soil bulk density increased most significantly in the places where the equipment turned [21].

It can take years or even decades for soils to recover naturally. It is known that some soils damaged during the First World War, still remain unsuitable for use [22, 23]. It takes from 1,500 to 7,400 years for the destroyed 20-centimeter layer of

humus to recover. In 100 years, only a layer of humus with a thickness of 0.5–2 cm is restored [24].

The results of land monitoring in the Donetsk and Luhansk regions, starting in 2014, indicate that the period of soil recovery after explosions (air bombs and shells of 80 and 120 mm caliber) for sandy soils is 5–7 years. Chernozems recover faster - in 2–3 years. Clay grows slowly with plants; recovery can last 5–7 years. On marl, vegetation is restored after 5–10 years [25].

According to many researchers, violations of the integrity of soils and soil cover as a result of military operations require carrying out additional soil and geographic research, mapping territories and studying the properties of disturbed soils for a detailed assessment of the real situation and long-term monitoring of each factor of negative impact on the soil cover. Only under these conditions, it is possible to determine the amount of losses and develop effective measures to restore the fertility of damaged arable soils [26, 27].

Currently, the specialists of the NSC "ISSAR named after O.N. Sokolovsky" on the basis of the results of pilot and experimental studies of the current state of the soil cover, the regulation on the methodological principles of assessing damage caused to the land fund and soils as a result of the war were improved [28]. In this regulation when establishing general damage, mechanical and physical degradation are considered as separate components.

Goal. Based on the study of the impact of military actions on the main agrophysical parameters of soils, to identify the peculiarities of the manifestation of their mechanical and physical degradation, and to propose effective anti-degradation measures that will make it possible to restore the fertility of damaged soils.

Research materials and methods. The research was carried out in the de-occupied territories of Kharkiv District, Kharkiv Region, where active hostilities took place, on three objects (fields): object 1 — near the village of Mala Rohan (Vilkhiv village community); object 2 — near the village Novy Korotych (Pisochn settlement community); object 3 — near the village Kutuzivka (Vilkhiv

village community). Arable soils were studied - typical heavy loamy chernozems on loess loam.

The selection of soil samples at the research sites was carried out in accordance with DSTU 4287:2004. Within the boundaries of object 1, samples were taken in funnels formed as a result of artillery fire with shells of different calibers (120 mm, 155 and 330 mm). Control samples were taken from the arable (0–30 cm) soil layer in an undamaged part of the field.

Within the object 2, samples were taken from the crater from the explosion of an aerial bomb weighing 100 kg in three places: in the upper part of the crater (at a depth of 30 cm), on the slope (up to 1500 cm) and in the lower part (up to 3000 cm). As a control sample, a sample from a depth of 0–30 cm of an undamaged part of the field was used. The granulometric composition of the studied soils was determined using a Mastersizer 3000E laser diffractometer. The soil bulk density at object 2 was determined by the calculation method, using linear and quadratic pedotransfer models developed by the employees of the soil geocophysics laboratory of the NSC "ISSAR named after O.N. Sokolovsky" [29], using soil indicators, in particular the content of physical clay and total humus.

Within object 3, the soil bulk density was determined by direct measurement in field conditions according to DSTU ISO 11272:2001 in layers 0–10 cm, 10–20, and 20–30 cm thick in two variants: I — within the agricultural field (control) and II — on the road, formed as a result of the movement of enemy military equipment.

STATISTICA 10 and MS Excel were used for data processing.

Research results. The peculiarities of the impact of military actions on the physical parameters of arable soils, in particular on their granulometric composition and soil bulk density, have been determined. First of all, military actions lead to the direct destruction of soil and plant cover, resulting in mechanical and physical degradation of soils and, as a result, a decrease or loss of their fertility.

Mechanical degradation. The analysis of data on the granulometric composition of soils at object 1 (Fig. 1), where samples were taken at the site of

the formation of funnels from artillery shells of various calibers (from 120 to 330 mm), showed that compared to the control, the average sand content (1 – 0.25 mm) and shallow (0.25 - 0.05 mm) fractions decreased by 1.3 - 3.0 and 2.3 - 11.1%, respectively. The dust content of coarse (0.05 – 0.01 mm) and medium (0.01 – 0.005 mm) fractions did not change significantly. The content of fine dust (0.005–0.001 mm) and silt (less than 0.001 mm) slightly increased — by 0.5–3.7% and 2.2–4.5%, respectively.

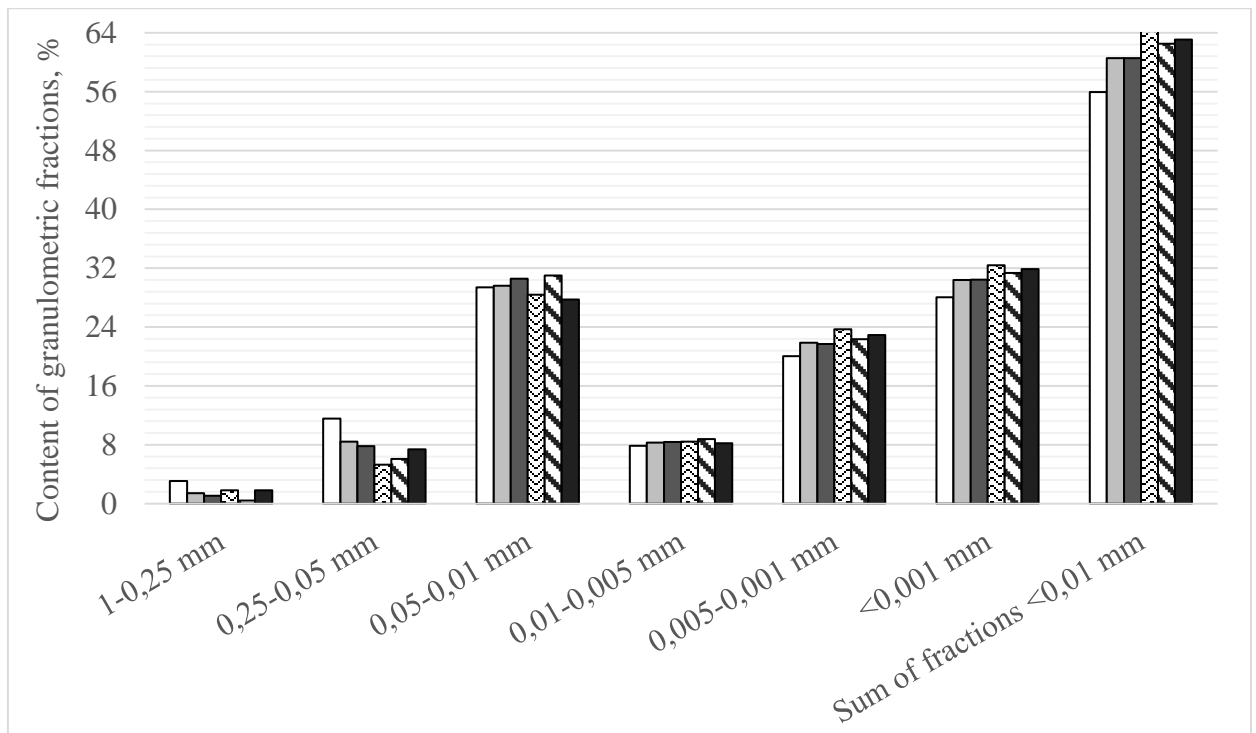


Fig. 1. The influence of military actions on the granulometric composition of the soil (object 1): □ — control (undamaged area, depth 0–30 cm); ◻ — funnel from an aerial bomb (depth 200 cm); ◼ — shell funnel (caliber 120 mm, depth 200 cm); ▨ — shell funnel (caliber 330 mm, depth 80 cm); ▩ — shell funnel (caliber 120 mm, depth 60 cm); ◼ — shell funnel (caliber 155 mm, depth 90 cm)

The highest content of sand of the medium fraction was recorded in the control variant (undamaged part of the field). The sand content of this fraction in the sample taken at the site of the aerial bomb explosion was almost 2.2 times less. The samples at the site of the formation of a funnel from a 120-mm projectile in a layer at a depth of 60 cm were characterized by its lowest content. The content of the silty fraction in the studied variants of the object varied from 28.05 to 32.41%. In general, there was a tendency to increase the content of dust particles in the soil

variants that were affected by the explosions, compared to the control. A similar trend was observed in relation to the content of physical clay: it increased by 2.82% in the funnel from the 120 mm caliber projectile compared to the control one and by 9% in the funnel from the 330 mm caliber projectile.

Analyzing the results of determining the granulometric composition of soils at object 2 (Fig. 2), (i.e. at the site of the origin of the funnel from the explosion of an aerial bomb weighing 100 kg, and examining the upper part, the slope and the lower part of this funnel), it was established that here, compared to the control, the content is reduced sand of medium and small fractions, as well as coarse dust. This is characteristic first of all for the lower part of the funnel.

At the same time, some increase was noted compared to the control of dust of medium and small fractions. This trend was also observed for the fraction of physical clay: its content increased by 6.69% in the lower part of the funnel, by 6.71% on the slope, and by 10.17% in the upper part. This indicates the redistribution of fractions of the investigated soils, which is a consequence of the movement and mixing of their horizons after the explosion of shells and has an extremely negative effect on the possibility of growing crops on damaged soils.

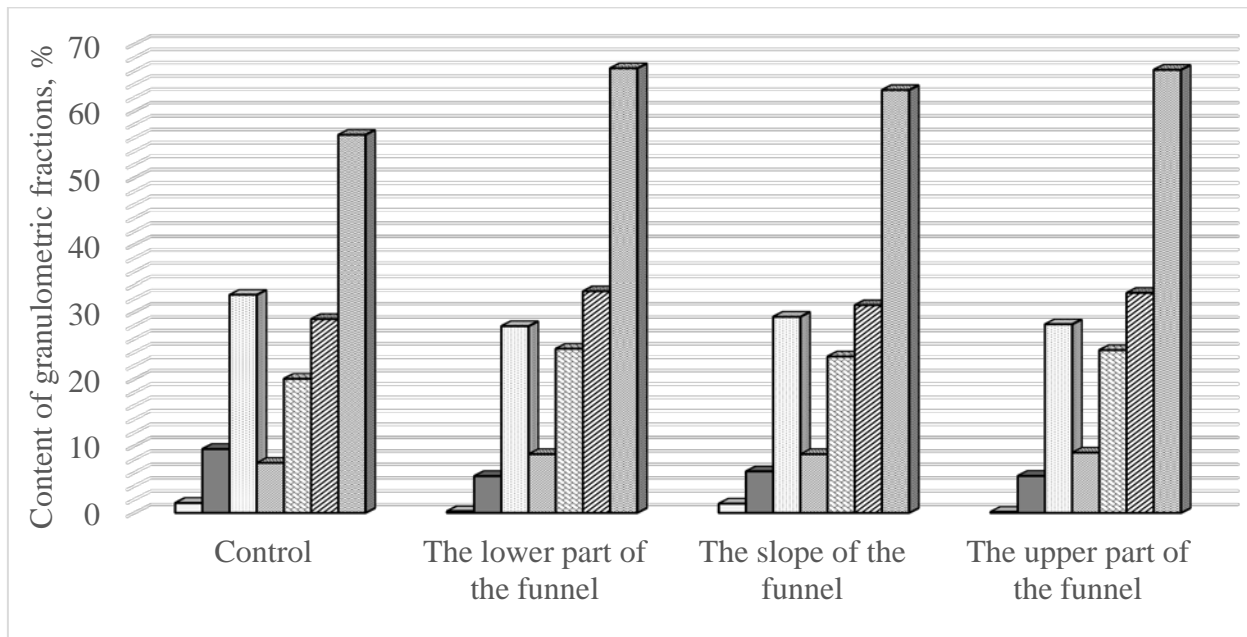


Fig. 2. The influence of military actions on the granulometric composition of the soil (object 2): □— 0–25 mm; ■— 0.05–0.01 mm; ▨— 0.005–0.001 mm; ▩— sum of fractions — < 0.01 mm; ▤— 0.25–0.05 mm; ▥— 0.01–0.005 mm; ▦— < 0.001 mm

Physical degradation manifested itself primarily in over-compaction of the studied soils. In particular, according to the results of determining the soil bulk density at object 2 by the pedotransfer modeling method, it was established that in the control sample this indicator is 1.28 g/cm^3 according to the linear model (Fig. 3, a), and according to the quadratic model 1.21 g/cm^3 (Fig. 3, b). Magnification compaction of $0.14\text{--}0.16 \text{ g/cm}^3$ was recorded on the damaged soil, namely in the lower part, on the slope and in the upper part of the funnel formed by the 330 mm projectile. A similar trend was observed for the values of the soil bulk density, calculated according to the quadratic model.

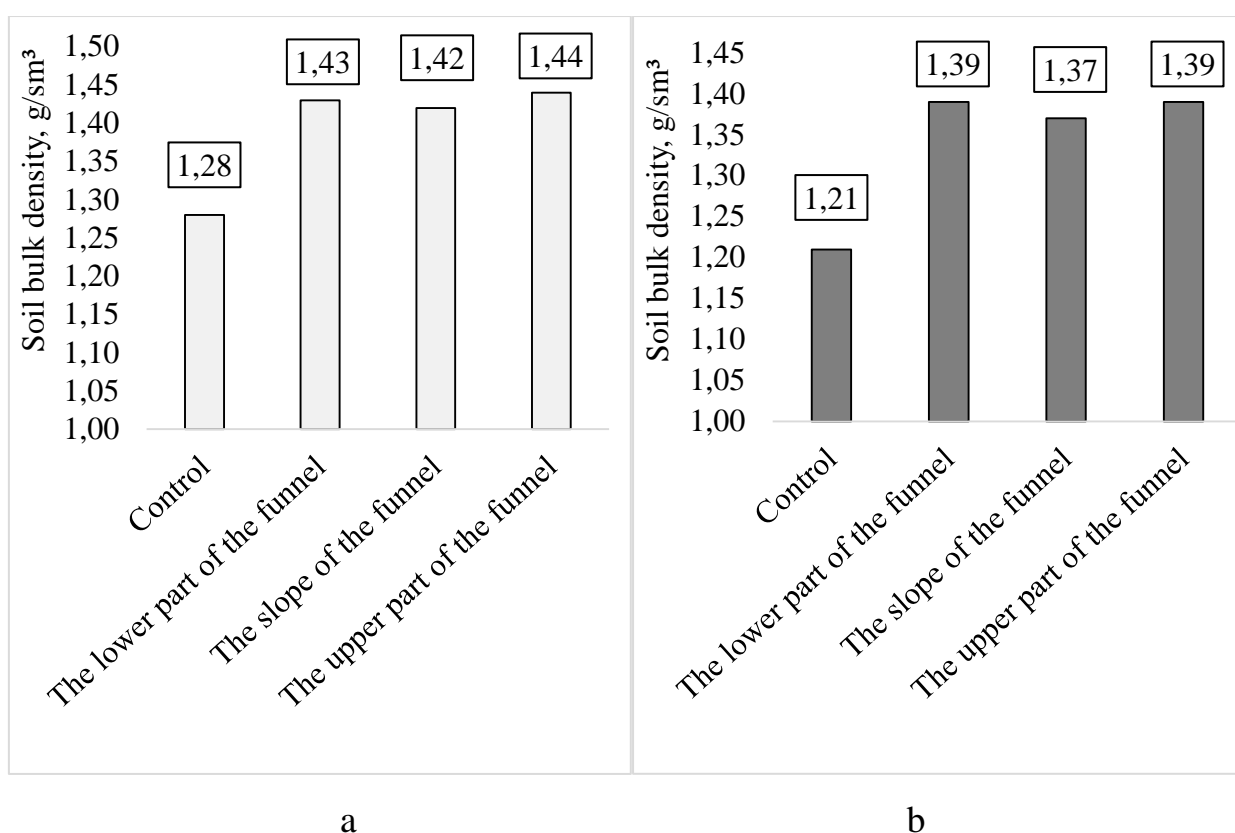


Fig. 3. The soil bulk density in the variant with a 330-mm projectile funnel, calculated by the pedotransfer modeling method (object 2): a — according to the linear model ($Z = 1.5606 - 0.0011 \cdot x - 0.0664 \cdot y$) ; b — according to the quadratic model ($Z = 1.6929 - 0.0103 \cdot x - 0.0645 \cdot y + 0.0001 \cdot x^2 - 0.0001 \cdot x \cdot y + 0.0006 \cdot y^2$, where Z is the soil bulk density, g/cm^3 ; x is the content of physical clay (particles smaller than 0.01 mm), %; y — humus content, %)

Determination of the soil bulk density in variant II indicates the occurrence of a process of overcompaction in the locations of military equipment: in the soil layer with a depth of 0–10 cm, the density increased by 0.39 g/cm^3 , and in the soil

layer with a depth of 10–20 cm by 0.17 g/cm^3 compared to the control sample (fig.4). The greatest compaction, up to 1.37 g/cm^3 , was recorded in the top layer of the soil, which in the future can become a significant obstacle to the germination and development of agricultural crops here.

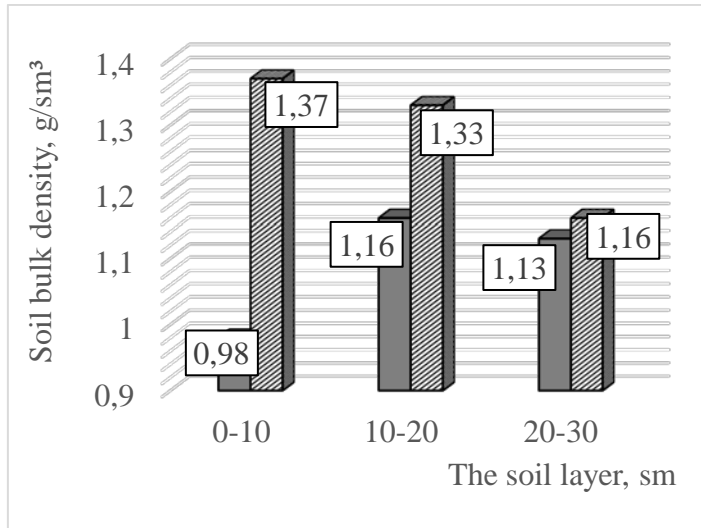


Fig. 4. The impact of the presence of military equipment on the soil bulk density (object 3):
 — control; — an artificial road

Measures to overcome the negative consequences of mechanical and physical degradation should be aimed at restoring fertility damaged arable soils. One such measure, in our opinion, is the use of deep tillage, the depth of which is determined by the density or hardness of damaged soils. Plantation plowing, deep meliorative loosening and splitting are agrotechnical melioration measures aimed at increasing the capacity of the root layer and improving the agrophysical properties of the soil.

Monitoring of arable soils should also be carried out with maximum coverage of the entire potentially affected area, using modern technologies, in particular, high-precision satellite images. This will make it possible to remotely detect and identify metal and explosive objects, demine and neutralize them, fix, digitize, and set the level of possible damage from each potentially dangerous area of the field. The use of elements of precision agriculture, which is introduced by many farms and agroholdings and provides an opportunity to save fertilizers, meliorants, seed material, fuel, etc., is quite effective during the war. The use of this technology will

help increase the level of soil fertility in the conditions of the negative degradation effect of military actions on the soil cover.

According to specialists from the Ukrainian Environmental Protection Group (UNCG), another way to revive damaged soils could be the creation of "red zones" in the territories where intensive military operations were conducted. Implementation of the listed measures at the same time, it will contribute to the fulfillment of the requirements of the legislation of Ukraine on land conservation and prevention of desertification, as well as the requirements of the EU Biodiversity Strategy until 2030.

Conclusions

Military actions lead to long-term and severe consequences, primarily to mechanical and physical degradation of arable soils. The redistribution of soil fractions damaged by shells of various calibers and air bombs was experimentally confirmed, which is manifested in an increase in the content of dusty particles and the fraction of physical clay. Substantial soil compaction on the slopes, in the lower and upper parts of the funnels formed by explosions has been proven air bomb. An increase in soil compaction was recorded at the site of the road formed as a result of the movement of military equipment, primarily in the upper 10-centimeter layer, which creates significant obstacles for the germination and development of agricultural crops.

In order to prevent degradation, it is proposed to carry out deep tillage and carry out agrotechnical melioration measures capable of improving the agrophysical properties of the soil and restoring its fertility. It is also necessary to develop a long-term program of gradual rehabilitation of damaged soils in the conditions of martial law and in post-war times. Such measures will contribute to obtaining sustainable harvests of agricultural crops in the future.

References:

1. Saljnikov, E. Mirschel, W., Prasuhn, V., Keller, T., & Mueller, L. (2022). Types of Physical Soil Degradation and Implications for Their Prevention and Monitoring. In: Saljnikov, E., Mueller, L., Lavrishchev, A., & Eulenstein, F.

(eds) *Advances in Understanding Soil Degradation*. (p. 43-73). Innovations in Landscape Research. Springer, Cham. https://doi.org/10.1007/978-3-030-85682-3_2.

2. Bouma, J (2019). How to communicate soil expertise more effectively in the information age when aiming at the UN Sustainable Development Goals. *Soil Use Manag*, 35(1), 32–38. <https://doi.org/10.1111/sum.12415>.

3. Kartini, N.L., Saifulloh, M., Trigunasih, N.M., & Narka, I.W. (2023). Assessment of Soil Degradation Based On Soil Properties and Spatial Analysis in Dryland Farming. *Journal of Ecological Engineering*, 24(4), 368-375. <https://doi.org/10.12911/22998993/161080>.

4. Voloshchuk, M. (2017). *Dehradatsiia hruntiv – hlobalna ekolohichna problema* [Source degradation – global environmental problem]. Visnyk of the Lviv University. Series Geography, 51, 63–70. <http://dx.doi.org/10.30970/vgg.2017.51.8738>. [In Ukrainian].

5. Zaitsev, Y., Sobko, V., Kozhevnikova, V., Lobanova, O., & Kyrylchuk, A. (2022). *Klasyfikatsiia protsesiv, shcho sprychynaiut dehradatsiiu zemelnykh uhid* [Classification of processes that cause land degradation]. *Agroecological journal*, 3, 150-159. <https://doi.org/10.33730/2077-4893.3.2022.266420>. [In Ukrainian].

6. Ferreira, C.S.S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. *Science of The Total Environment*, 805, 150106. <https://doi.org/10.1016/j.scitotenv.2021.150106>.

7. Medvedev, V.V., Plisko, I.V., Krylach, S.I., Nakisko, S.H., & Uvarenko, K.Yu. (2020) *Fizychna dehradatsiia ornykh gruntiv Ukrainy (otsiniuvannia, profilaktyka, pryzupynennia)* [Physical degradation of arable soils of Ukraine (assessment, prevention, suspension)]. Kharkiv: FOP Brovin O.V. [In Ukrainian].

8. Decyk, O., & Alekseev, V. (2022) Uriatuvaty ukraïnski chornozemy. Yak viina znyshchuie rodiuchist nashykh zemel i shcho z tsym robyty [Save

Ukrainian Black Soils. How war destroys the fertility of our lands and what to do about it]. Retrived from https://antikor.com.ua/ru/articles/597351-spasti_ukrainskie_chernozemy._kak_vojna_unichtohaet_plodorodie_nashih_zemel_j_i_chno_s_etim_delatj

9. Rawtani, D., Gupta, G., Khatri, N., Rao, P. K., & Hussain, C. M. (2022) Environmental damages due to war in Ukraine: A perspective. *Science of The Total Environment*, 850, 157932. <https://doi.org/10.1016/j.scitotenv.2022.157932>.

10. Pata, U. K., Kartal, M. T., & Zafar. M. W. (2023) Environmental reverberations of geopolitical risk and economic policy uncertainty resulting from the Russia-Ukraine conflict: A wavelet based approach for sectoral CO₂ emissions. *Environmental Research*, 231(1), 116034. <https://doi.org/10.1016/j.envres.2023.116034>.

11. Hupy, J. (2008) The Environmental Footprint of War. *Environment and History*, 14 (3), 405-421. <https://doi.org/10.3197/096734008X333581>.

12. Olson, K., & Speidel, D. (2020). Review and Analysis: Successful Use of Soil Tunnels in Medieval and Modern Warfare and Smuggling. *Open Journal of Soil Science*, 10 (5), 194-215. <https://doi.org/10.4236/ojss.2020.105010>.

13. Macharia, H.M. (2016). The Impact of Military Exercises and Operations on Local Environment. *Journal of language, technology & entrepreneurship in Africa*, 7(2), 140-152.

14. Certini, G., Scalenghe, R., & Woods, W.I. (2013). The impact of warfare on the soil environment. *Earth-Science Reviews*, 127, 1-15. <https://doi.org/10.1016/j.earscirev.2013.08.009>.

15. Islam, E., Yang, X., He, Z., & Mahmood, Q. (2007). Assessing potential dietary toxicity of heavy metals in selected vegetables and food crops. *J. Zhejiang Univ. Sci*, 8, 1–13. <https://doi.org/10.1631/jzus.2007.B0001>.

16. Golubtsov, O., Sorokina, L., Sploditel, A., & Chumachenko, S. (2023). *Vplyv viiny rosii proty Ukrainy na stan ukrainskykh gruntiv*. Rezultaty analizu [The impact of russia's war against Ukraine on the state of Ukrainian soils.

Analysis results]. Kyiv: PO "Center for Environmental Initiatives "Ekodia". [In Ukrainian].

17. Reyes, M.R., Raczkowski, C.W., Reddy, G.B., & Gayle, G.A. (2005). Effect of wheel traffic compaction on runoff and soil erosion in no-till. *Applied Engineering in Agriculture*, 21(3), 427-433. <https://doi.org/10.13031/2013.18462>.

18. Broomandi, P., Guney, M., Kim, J.R., & Karaca, F. (2020). Soil Contamination in Areas Impacted by Military Activities: A Critical Review. *Sustainability*, 12(21), 9002. <https://doi.org/10.3390/su12219002>.

19. Whitecotton, R., David, M., Darmody, R., & Price, D. (2000). Impact of Foot Traffic from Military Training on Soil and Vegetation Properties. *Environmental Management*, 26, 697–706. <https://doi.org/10.1007/s002670002224>.

20. Müller, C.R., Pedron, F.A., Barbosa, B.W., Rodrigues, M.F., & Schenato, R.B. (2021). Soli degradation after traffic of a military combat vehicle leopard 1A5BR. *Ciência e Natura, Santa Maria*, 43(87), 1-31. <https://doi.org/10.5902/2179460X62685>.

21. Retta, A., Wagner, L.E., Tatarko, J., & Todd, T.C. (2013). Evaluation of bulk density and vegetation as affected by military vehicle traffic at Fort Riley, Kansas. *Transactions of the ASAE*, 56(2), 653-665. <https://doi.org/10.13031/2013.42687>.

22. Thestorf, K., & Makki, M. (2022). Soils and landforms of war — Pedological investigations 75 years after World War II. *Geomorphology*, 407, 108189. <https://doi.org/10.1016/j.geomorph.2022.108189>.

23. Bardgett, R. (2016). Soil and War. *Earth Matters: How soil underlies civilization*. (pp.105-134). Oxford University Press. <https://doi.org/10.1093/oso/9780199668564.003.0010>.

24. Kravchenko O. (Eds.) (2015). *Voienni dii na skhodi Ukrainy — tsyvilizatsiini vyklyky liudstvu* [Military actions in the east of Ukraine — civilizational challenges to humanity]. Lviv: EPL. [In Ukrainian].

25. Blaga, A.B., Zagorodniuk, I.V., Korotkyi, T.R., Martynenko, O.A., Medvedeva, M.O., & Parkhomenko, V.V. (Bushenka, A.P. (Ed.)). (2017). *Na mezhi vyzhyvannia: znyshchennia dovkillia pid chas zbroinoho konfliktu na skhodi Ukrainy* [On the edge of survival: destruction of the environment during the armed conflict in eastern Ukraine]. Kyiv: Ukrainian Helsinki Union for Human Rights. [In Ukrainian].

26. Sploditel, A., Golubtsov, O., Chumachenko, S., & Sorokina, L. (2023). *Praktyky z vidnovlennia zemel* [Land reclamation practices]. *Zabrudnennia zemel vnaslidok ahresii rosii proty Ukrainy* [Land pollution as a result of russia's aggression against Ukraine].(pp.58-98). Kyiv: PO "Center for Environmental Initiatives "Ekodia". [In Ukrainian].

27. Pozniak, S. (2015). Soils in the modern changing world. *Visnyk of the Lviv University. Series Geography*, 49, 275–279. <http://dx.doi.org/10.30970/vgg.2015.49.8644>. [In English].

28. Balyuk, S.A., Kucher, A.V., Solokha, M.O., Solovei, V.B., Smirnova, K.B., Momot, G.F., & Levin, A.Ya. (2022). *Vplyv zbroinoi ahresii ta voiennykh dii na suchasnyi stan hruntovoho pokryvu, otsinka shkody ta zbytkiv, zakhody z vidnovlennia: nauk. dop.* [The influence of armed aggression and military operations on the current state of the soil cover, damage and loss assessment, recovery measures: Sci. add.]. Kharkiv: FOP Brovin O.V. [In Ukrainian].

29. Medvedev, V., Plisko, I., & Blgun, O. (2015). *Dosvid pedotransferneho modeliuvannia u doslidzhenniakh fizyky gruntiv* [Experience of pedo transfer simulation in probes of soil physics]. *Bulletin of Agricultural Science*, 1, 17-24. [In Ukrainian].