# Impact of military operations on agricultural soils

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***Abstract.*** *The article examines and analyses the impact of armed aggression and hostilities on the soil cover, in particular, damage and destruction of the fertile soil layer as a result of detonation of various explosive objects (missiles, bombs, artillery shells, etc.) and movement of military equipment and its contamination with harmful substances contained in explosives and fuels and lubricants.*
***KEYWORDS: AGRICULTURAL SOILS, CONTAMINATION, RECLAMATION, SINKHOLE***

Soils are the main means of producing plant-based agricultural products at any stage of their development. The main feature of agricultural soils is their fertility, which is primarily determined by the structural condition of the soil environment. Ukraine's soil cover consists primarily of black soil, with an area of more than 24 million hectares, with the share of Ukrainian black soil among European soils at around 30% and 9% of the world's total [1].

Soil formation in Ukraine has a distinct zonal character, with changes in soil and climatic conditions occurring at relatively short distances.

The predominantly heavy particle size distribution of chernozem soils leads to increased moisture capacity and nutrient availability, which determines the relatively high natural fertility of soils without fertilisation, which is important during the period of martial law. The parameters of agro-soil potentials of natural soil fertility indicate the possibility of an annual gross harvest of grain crops of more than 50 million tonnes, and with effective fertility - 70-90 million tonnes or more, which is important for the country's food security and export opportunities. Even without taking into account the temporarily occupied territories, Ukraine's soil cover can produce more than 40 million tonnes of grain without fertilisers, which indicates a significant resource potential of soils, provided that the high culture of agriculture inherent in the Ukrainian ethnic group and multiplied by scientific achievements is maintained [2, 3].

As a result of the hostilities, Ukraine's soil resources have been significantly destroyed, their quality has deteriorated, and degradation processes have intensified, with a number of mechanical, physical and chemical impacts on the soil cover. Such impacts lead to the destruction of the structure and functions of the soil ecosystem, and deterioration of physical and geochemical properties.

Land pollution is divided into three main types. The first is mechanical pollution - when the structure of the soil cover changes. The fertile layer is incredibly valuable because it takes thousands of years to form and cannot be restored quickly. When it is destroyed or mixed with other layers - through digging trenches and trenches or explosions that literally turn the earth upside down - it loses its properties, retains moisture less well and becomes less suitable for growing crops. Mechanical contamination is also caused by the movement of military equipment, which compacts the soil and makes it more arid and prone to weathering or leaching - so-called wind or water erosion. The second type is physical contamination, i.e. changes in its physical properties. For example, the same military equipment also causes vibrations, and explosions or fires, in addition to direct destruction, disrupt the temperature regime, which is dangerous for soil biodiversity. And while at first glance the earth is not a very lively place, it is a whole centre of life. And the fertility and health of the soil depends on these organisms. The third type of pollution is chemical. This includes fuel leaks, combustion products that settle on the soil from the air, and toxins that get there through explosives in shells. This is a problem for the health of not only the land but also people. Hazardous substances can get through the soil into the water or plants grown on it, and from there into the bodies of people who drink or eat toxic products. It has been proven that heavy metals can contribute to nervous system or haematopoietic disorders, and some can even have a carcinogenic effect [4, 5].

Military operations also result in acidification or alkalisation of soils (physical and chemical pollution), biological pollution (loss of agronomically useful communities in the structure of soil biota, reduction of soil biochemical activity, deterioration of sanitary conditions, soil toxicity, bioindication of chemical pollution of the soil environment) and contamination of the soil cover by products of military activities, surface clutter (remnants of military equipment, defensive structures, shrapnel, etc.) [6].

Enemy aircraft and artillery have the greatest impact on agricultural land and soil cover, accounting for about 80 per cent of the impact. As a result of rocket and artillery shelling, the fields are covered with craters (craters) from the explosions of shells, mines, and rockets. The craters are of different diameters and depths. Craters from 220 mm calibre shells (Uragan MLRS) have a diameter of about 7 m, craters from 152 mm calibre shells (howitzers, self-propelled guns) have a diameter of 4 m to 6 m, craters from 120 mm calibre shells (Grad MLRS) have a diameter of 2.5 to 3.5 m, craters from 82 mm calibre shells (mortars) have a diameter of about 1 m. The depth of the craters in the fields ranges from 30 cm (82 mm mortar) to 5 m (cruise missiles), and the soil remaining at the impact site is turbulent, subject to dynamic compaction, and contains numerous metal fragments with residues of explosive toxic substances, i.e., deterioration of physical properties of the soil, changes in the particle size distribution, compaction and disintegration due to a decrease in the content of agronomically valuable fractions, etc.

Heavy metals are contained in all munitions, which accumulate in the top 10 cm of soil and are bioavailable to surrounding ecosystems. High-order detonations cause small metal fragments of projectiles to be scattered over different distances, depending on their power and, accordingly, their radius of flight. Partial detonations scatter the largest fragments of the projectile body. Analysis of the soil in the areas where small arms were used in Ukraine revealed elevated levels of manganese, iron and aluminium. However, the highest levels were found for lead, copper, cadmium, mercury, arsenic, and nickel. Tungsten was also detected in a few samples. Metals can also be deposited by pyrotechnic and smoke shells. Pyrotechnics most often also contain barium, antimony, strontium, copper, magnesium, manganese, chromium and lead.

Other inorganic pollutants are inorganic compounds of other metals when they reach potentially harmful concentrations (Fe, Cl, AI, Sr, Mn, S), as well as salts, cyanides and other less common inorganic compounds.

The analysis of soil samples directly in the crater and in the area of impact on the soil cover after the hostilities revealed that concentrations of cadmium, chromium and lead were found in the craters (in craters of 120...125 mm ammunition, the cadmium concentration coefficients are approximately 4...17 clarks from the background. 17 clarks from the background, 82 mm – 4 clarks, 152...155 mm shells – 2...18 clarks, aircraft bombs – 5...13 clarks; lead concentration coefficients are approximately 4...22 clarks in the places of rupture of 120...125 mm ammunition, 2.6...4 clarks – 152...155 mm, 2.7 clarks – 82 mm ammunition and 2.7...11 clarks – aircraft bombs). The highest concentration of cadmium was observed on the slopes of the crater, while chromium was found at the bottom. It should be noted that the type of ammunition was identified either by the debris near the crater or by the size of the crater. In addition, it is impossible to safely carry out mechanised work with agricultural machinery in the fields, as accidents can occur when tilling or harvesting as a result of tractor, combine or machinery wheels falling into craters. Fig. 1 shows the appearance of craters from aerial bombs, which were used as an example to study the impact of military operations on the soil cover.

*a)*

*b)*

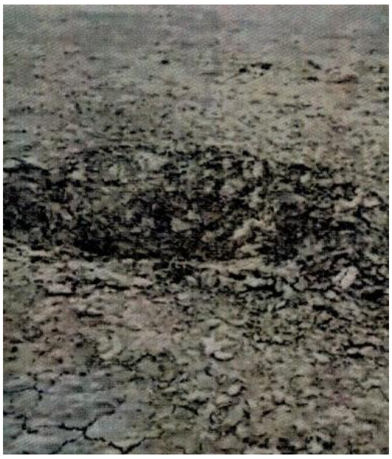
***Figure 1.*** *The appearance of bomb craters:*
*a) diameter is about 10 m; b) diameter is about 8 m*

In Fig. 2 shows eruptions from explosions of artillery shells.

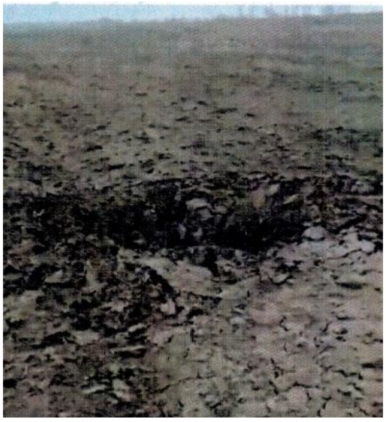
Explosions of thermobaric munitions also caused significant damage. Shelling with such projectiles releases massive flames that destroy organisms on the ground and soil biodiversity. Due to the sharp change in temperature, the water balance is disrupted. They spray a flammable substance into the air, which then explodes, creates a flame and destroys all life. This is dangerous for soils not only because of fires. A sharp change in temperature also disrupts the heat and water regime, which damages fertility and the ability of soils to recover.

Other important impacts on the soil cover are the consequences of explosion, detonation or burning of heavy machinery on agricultural land. Based on the results of the soil particle size distribution analysis, it was found that in the areas of heavy machinery burning and fuel and lubricant leakage, the content of physical clay decreased.

The movement of heavy military equipment causes soil compaction. The density of the structure of typical chernozem was determined in the field, where intense hostilities took place, and the density parameters were determined (according to DSTU 180 11272-2001) at depths of 0-10, 10-20 and 20-30 cm in two variants: 1 - within an agricultural field (control) that was not cultivated and 2 - on a road artificially formed as a result of the passage of enemy military equipment. It was found that the density of the soil structure within the arable layer ranged from 0.98 to 1.16 g·cm$^{-3}$. At the same time, the lowest density was determined for the top layer of soil 0-10 cm, while in the layer 10-20 cm there is an increase in density by 0.18 g·cm$^{-3}$, which is evidence of the existence of a "plough sole".



*a)*



*b)*

***Figure. 2.*** *Bursts from explosions of artillery shells:*
*a) 152...155 mm shells; b) 120...125 mm shells*

At the same time, a significant increase in the density of soil structure was recorded in the areas of artificially created paths for military vehicles (second variant). The highest compaction – 1.37 g·cm$^{-3}$ – was recorded in the topsoil (0-10 cm), which is 0.39 g·cm$^{-3}$ higher than in the control (uncompacted field). This is a significant obstacle to growing crops in the post-war period (as is known, an increase in soil density by 0.1 g·cm$^{-3}$ leads to a decrease in grain yields of up to 2 c·ha$^{-1}$ of grain). Dense soil has a lower rate of both water penetration and drainage. This is because large pores move water down through the soil more efficiently than smaller pores. In compacted soils, gas exchange slows down, causing an increased likelihood of aeration problems.

To he restoration and preservation of the fertility of agricultural soils in Ukraine, which have been destroyed by military operations, is a very acute, global and urgent problem for the entire agricultural sector, which has a state priority. It is necessary to restore the relief of agricultural land, levelling and reclaiming it, i.e. to return the soil to a healthy balance and fertility. To do this, it is necessary to remove or clean the damaged soil layer in the sinkhole. If dangerous concentrations of heavy metals and other hazardous substances are found on the surface of the sinkhole, the removed contaminated soil layer must be disposed of. If the removed layer of the crater surface contains an acceptable concentration of pollutants, the removed layer can be left at the bottom of the crater.

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