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ASSESSMENT AND PREDICTION OF AGROCHEMICAL CHANGES IN SOILS AFFECTED BY MILITARY ACTIVITIES AS A BASIS FOR DEVELOPING DETOXIFYING FERTILIZERS

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Abstract: The study investigates changes in the agrochemical status of soils in the border areas of the Sumy region under the impact of military activities. Based on a comparison of agrochemical passport data from 2021 and the results of repeated soil sampling, a consistent trend toward increasing technogenic contamination and degradation of the ecological state of soils has been identified. The feasibility of applying organo-mineral compositions based on bioash and anaerobic digestate as an effective approach for soil detoxification and fertility restoration has been substantiated. A scientifically grounded approach to the development of granulated fertilizers with combined detoxifying and restorative effects is proposed.

Keywords: technogenic contamination, heavy metals, explosive residues, toxic organic compounds, remediation, organo-mineral biocomposites, digestate, bioash.

The war in Ukraine has led to large-scale degradation of soils and their contamination with toxic substances, posing threats to food security at both national and global levels [1]. Military activities create a complex technogenic impact on soils due to ammunition detonations, fuel spills, and infrastructure destruction, resulting in the accumulation of heavy metals, petroleum hydrocarbons, and explosive residues [2]. In areas of active hostilities, concentrations of heavy metals may significantly exceed natural background levels [3].

Particular attention should be paid to assessing changes in the agrochemical status of soils in the border regions of Ukraine, which have experienced the highest technogenic pressure. One such area is the Bilopillia district of the Sumy region, located in close proximity to zones of active hostilities.

Agrochemical passport data for agricultural lands of Bilopillia Agrosvit LLC (Kalchenkivska Territorial Community), collected in 2021 prior to the full-scale war in Ukraine, were used as a baseline for comparison. A total of 15 soil samples were analyzed, providing a representative characterization of the initial agrochemical and ecological conditions. The results indicate that, as of 2021, the soils were characterized by relatively favorable properties: soil pH ranged from 6.09 to 7.43, humus content was 4.62–4.86%, and nutrient availability varied widely (nitrogen – 112–151 mg/kg, phosphorus – 51–200 mg/kg, potassium – 62–180 mg/kg). All samples contained detectable levels of heavy metals, particularly cadmium (0.07–0.09 mg/kg) and lead

(1.15–2.75 mg/kg), indicating a background technogenic load even in the pre-war period. The integrated ecological and agrochemical index ranged from 24 to 34 points, corresponding to a moderate level of soil ecological condition.

After more than four years of military impact, soil conditions were reassessed. A total of 15 soil samples were collected from the same locations for comparative and quantitative evaluation of changes induced by military activities. Particular attention was given to contamination by key toxicants, including heavy metals (Pb, Cd, Hg), explosive residues, and toxic organic compounds, which pose significant ecological and agricultural risks.

The results show a significant increase in soil heavy metal concentrations after prolonged military impact. Lead concentrations increased to 12–65 mg/kg, with some local hotspots exceeding these values. Cadmium levels rose to 0.3–1.2 mg/kg, representing several-fold increases compared to baseline conditions. Mercury, which was previously undetected or below detection limits in the pre-war period, was detected at levels of 0.02–0.08 mg/kg, indicating technogenic input. A distinct group of contaminants is represented by explosive residues, which were absent in the initial soil state. Analytical results revealed concentrations ranging from trace levels to 0.5–3.0 mg/kg, depending on the intensity of military impact. Toxic organic compounds, including incomplete fuel combustion products and polycyclic aromatic hydrocarbons, were also detected, contributing to additional environmental pressure.

Shifts in agrochemical soil characteristics indicate a disturbance of natural soil balance. The integrated ecological-agrochemical index declined to 15–28 points, reflecting a deteriorated and locally stressed condition, and confirming the transition from a relatively stable state to technogenic degradation.

Currently, existing remediation approaches do not provide comprehensive solutions for multicomponent contamination. Physicochemical methods are effective but costly and may cause secondary pollution, whereas biological approaches are more environmentally friendly but slower and dependent on external conditions [2]. A promising approach involves organo-mineral compositions based on biogenic materials, particularly anaerobic digestate, which improve soil physicochemical properties and promote toxicant transformation [4]. Due to humic substances and dissolved organic fractions, digestate can immobilize heavy metals by forming stable complexes [5, 6], although its effectiveness depends on application conditions and material modification [7].

An additional challenge is contamination by explosive compounds, such as hexogen, which suppress biological activity and disrupt soil biochemical processes [8]. Despite progress in biological and combined remediation, their effectiveness remains limited [9].

Therefore, existing remediation approaches do not ensure comprehensive restoration of soils in military-affected areas, necessitating new scientifically grounded solutions. This study proposes and experimentally substantiates an approach to developing granular detoxifying fertilizers based on bioash and anaerobic digestate through systematic variation of composition. Laboratory investigations evaluate sorption properties and establish composition–property relationships governing detoxification and nutrient enrichment of soils.

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Анотація: Досліджено зміну агрохімічного стану ґрунтів прикордонних територій Сумської області під впливом військових дій. На основі порівняння даних агрохімічних паспортів 2021 року та результатів повторного відбору ґрунтових проб встановлено стійку тенденцію до зростання техногенного забруднення та деградації екологічного стану ґрунтів. Обґрунтовано доцільність застосування органо-мінеральних композицій на основі біозоли та анаеробного дигестату як ефективного інструменту детоксикації та відновлення родючості. Запропоновано науково обґрунтований підхід до створення гранульованих добрив із комплексною детоксикаційно-відновлювальною дією.

Ключові слова: техногенне забруднення, важкі метали, вибухові речовини, токсичні органічні сполуки, ремедіація, органо-мінеральні біокомпозити, дигестат, біозола.