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Density as a Diagnostic Criterion for the Degradation of Typical Chernozems Under the Influence of Combat Operations

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Abstract: The relevance of the study is determined by the need to assess the physical degradation of soils caused by military operations covering significant areas of typical chernozem. Soil density is one of the key indicators of disruption to its structural condition, water regime, and biological activity, especially under conditions of technogenic stress. The aim of the study was to determine the nature of changes in soil density under different land use types, including natural, agrogenic, and technogenic areas, in particular those affected by military equipment and pyrogenic stress. The study used a comparative analysis of soil profile density (0–40 cm) for six variants: fallow land with partial burning, natural fallow land, road, plowed road, arable land, and military equipment parking area. The measurements were taken at depths of 0–10, 10–20, 20–30, and 30–40 cm, followed by statistical generalization. The results showed that the highest density values (up to 1.51 g·cm^{-3}) were observed on road areas and equipment parking areas, indicating deep technogenic compaction. Natural variants have the lowest values (≈1.22–1.25 g·cm^{-3}), which corresponds to the preserved structure of the soil cover. Agrogenic areas show partial restoration of the top layer, but compaction remains in deeper horizons. Therefore, soil density is a reliable diagnostic criterion for physical degradation, especially in conditions of military impact. The data obtained can be used to monitor soil condition, plan restoration measures, and assess environmental risks in areas that have been subjected to combat impact.

Keywords: degradation; soil density; porosity; typical chernozem; combat actions

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1. Introduction

Physical degradation of soils, in particular their compaction, is one of the most common forms of soil disturbance, leading to reduced water permeability, poor aeration, destruction of structure, and reduced biological activity. Under natural conditions, these processes occur slowly, but intensive anthropogenic stress, especially related to agricultural production and technogenic impact, significantly accelerates their development. In the context of modern warfare, the scale of physical degradation is increasing significantly due to the movement of heavy equipment, the construction of

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fortifications, pyrogenic processes, and mechanical destruction of the soil cover, which creates local and regional pockets of disturbance in the structure of the chernozem profile. Such changes are long-term and can significantly affect the productivity of agricultural landscapes, the stability of ecosystems, and the possibilities for further recultivation. In this context, soil density is one of the most sensitive and indicative diagnostic criteria, allowing for a quantitative assessment of the degree of physical degradation and tracing the differences between natural, agrogenic, and technogenically transformed areas. That is why studying changes in the density and porosity of typical chernozems under different land use regimes is important for understanding the nature of disturbances, determining their depth, and developing effective restoration measures.

Soil compaction is considered one of the key processes of physical degradation, manifested in a decrease in pore space volume and an increase in bulk density. The ability of soil to resist compaction is determined by its structure, granulometric composition, moisture content, and organic matter content (Nalobina et al., 2023). Under natural conditions, compaction can occur as a result of drying, freezing, and other climatic factors, while anthropogenic loads, in particular the movement of heavy equipment, can cause a sharp and profound disruption of the pore space and physical properties of the soil (Shaheb et al., 2021). One of the main consequences of compaction is the transformation of pore space — a decrease in the proportion of macropores and an increase in the proportion of mesopores and micropores. This leads to a decrease in hydraulic conductivity, air permeability, and disruption of biogeochemical cycles, in particular carbon and nitrogen (Nawaz et al., 2013). Excessive compaction of the upper soil horizons also causes waterlogging and oxygen deficiency for root systems, which negatively affects plant growth and productivity (Havryk and Tsyuk, 2024).

The physical properties of soils are spatially heterogeneous and dynamic, especially in agroecosystems, where they change during the growing season under the influence of tillage, changes in moisture content, and biological activity. This necessitates a systematic approach to their study and consideration of seasonal dynamics (Keller and Håkansson, 2010). Many scientific works devote considerable attention to the quantitative assessment of the physical and biotic properties of soils under different land use regimes. Researchers have also established a relationship between compaction parameters and soil resource management practices (Nalobina et al., 2023). International scientific studies also confirm that intensive farming, excessive use of machinery, and failure to adhere to the principles of sustainable management lead to the formation of plow pan, reduced infiltration capacity, and deterioration of soil structural stability (Shaheb et al., 2021; Keller et al., 2019; FAO, 2022).

A separate area of contemporary research concerns the impact of military action on soil cover. In many countries around the world—in the Middle East, the Balkans, and Central Africa—military operations lead to the destruction of vegetation cover, changes in micro-relief, increased erosion processes, and deep technogenic soil compaction (Olson et al., 2020; Macharia, 2016). The mechanical impact of heavy tracked and wheeled vehicles, explosive loads, and pyrogenic processes cause destructurization, destruction of aggregates, and the formation of excessively compacted layers that persist for a long time (Golubtsov et al., 2023). For agricultural land, this means a deterioration in agrophysical properties, reduced water permeability, and the formation of local areas of overcompaction in places where equipment is parked and on turning strips (Plisko and Romanchuk, 2025). According to estimates by international organizations, the proportion of degraded land in the world continues to grow, and military action is one of the factors accelerating these processes (Honcharova, 2024). In Ukraine, according to recent studies, about 20% of agricultural land has been significantly affected by military action, which highlights the need for a detailed study of the physical condition of soils in combat zones (Balyuk et al., 2024).

Despite the significant volume of scientific works devoted to the study of the physical properties of soils and the mechanisms of their compaction, existing studies do not pay sufficient attention to a comprehensive assessment of profile changes in the density of chernozems under specific conditions of military stress. Most of the work focuses on agrogenic or natural systems, while technogenic influences associated with the movement of heavy equipment, pyrogenic processes, local destruction of soil cover, and the formation of excessively compacted areas have been studied only fragmentarily.

In addition, the depth of penetration of technogenic compaction, the differences between various types of military impact, and the relationship between soil density, porosity, and stability in post-conflict landscapes have not been sufficiently studied. Comparative data on natural, agrogenic, and technogenically transformed areas within a single soil type are limited, which complicates the formation of a comprehensive understanding of degradation processes.

It is precisely these unresolved scientific questions that necessitated this study, aimed at quantitatively assessing changes in the density and porosity of typical chernozems under different land use regimes and different types of military impact.

2. Materials and Methods

The study aimed to assess the physical properties of typical chernozems under various land use conditions and anthropogenic loads, particularly those associated with military actions. Field and laboratory work was carried out during 2025 as part of the scientific project "Impact of Military Actions on the Soil Cover and Soil Quality in Ukraine" (state registration number 0124U005030). Samples for analysis were selected from six variants representing natural, agrogenic, and technogenically transformed areas within the Kharkiv region. This approach allowed us to cover a wide range of conditions that reflect different types of anthropogenic and military impacts on the soil cover.

The first variant (burnt fallow) is represented by an area where, as a result of military operations, the grass cover was partially burnt and the topsoil underwent pyrogenic degradation. The second variant (natural fallow) served as an absolute control and was characterized by stable natural grass cover that had formed over more than 70 years without mechanical intervention. The third variant (compacted road) covered a section of a temporary road laid across an arable field, which had been repeatedly traversed by heavy military equipment. The fourth variant (ploughed road) modeled the after-effects of anthropogenic stress through surface cultivation of the compacted road. The fifth variant (arable land) was characterized by prolonged agrogenic use for over 100 years and was not affected by military action. The sixth variant (equipment parking area) is represented by a section of temporary storage of military equipment, where additional contamination of the surface layer with fuel and lubricants was detected.

Soil samples were taken using a drill in four layers: 0–10, 10–20, 20–30, and 30–40 cm. This approach allowed us to assess the vertical differentiation of physical properties, since the upper humus-accumulative horizon of chernozems is most sensitive to mechanical stress and disturbances. Three replicates were selected for each variant, which ensured the possibility of statistical generalization and increased the reliability of the results obtained.

The density of soil composition was determined by direct sampling in field conditions using cylinders with a volume of 100 cm^3, which allowed preserving the natural structure of the soil, followed by drying and weighing in the laboratory in accordance with DSTU ISO 11272:2001. The density of the solid phase was determined by the pycnometric method in accordance with DSTU 4745:2007, which is based on measuring the mass of the soil sample and the volume of displaced liquid in the pycnometer. Based on the obtained values, the total porosity, space, and volume of pores occupied by hygroscopic water were calculated using generally accepted formulas (Petrenko et al., 2013):

total porosity: $P = 100 \times (1 - d_v \times d^{-1})$;

pore space: $K_n = P \times (100 - P)^{-1}$;

volume of pores occupied by hygroscopic water: $P_{MG} = MG \times d_v \times 1.5^{-1}$,

where d_v is the density of soil composition, d is the density of the solid phase, MG is the maximum hygroscopicity in percent by mass, and 1.5 g cm^{-3} is the density of hygroscopic water.

Statistical analysis was performed using analysis of variance (ANOVA). The least significant difference ($LSD_{0.05}$) was determined using Fisher's criterion with three replicates (n = 3) to identify significant differences between variants. The calculations were performed in the Microsoft Excel (Microsoft 365 Education) software environment. The significance level was set at $p<0.05$.

3. Results and Discussion

Analysis of the profile distribution of density, solid phase density, total porosity, and other indicators of pore space allows both surface and deep soil disturbances to be identified. Since density is an integral indicator reflecting the state of the aggregate structure, the degree of pore space preservation, and the level of mechanical impact, its changes are a key diagnostic criterion for physical degradation. That is why comparing variants with natural, agrogenic, and technogenic loads allows us to trace the patterns of soil profile transformation and identify the most vulnerable horizons.

Particular attention was paid in the studies to assessing the depth of penetration of technogenic compaction and the differences between various types of impact. Comparison of the variants showed that the intensity and nature of the disturbances depend not only on the load force, but also on the duration of its action, the type of equipment, soil moisture, and the previous state of agrophysical properties. Analysis of the vertical profile made it possible to determine whether the changes are limited to the surface layers or extend to a depth of 20–40 cm, which is important for assessing the long-term consequences of degradation and the potential for natural or artificial recovery. Below is a detailed description of the data obtained for each variant and their interpretation, taking into account the peculiarities of the formation of the physical state of typical chernozems (Figure 1, Table 1).

On the fallow land that had been exposed to pyrogenic effects, moderate compaction of the top layer (0–10 cm) was observed. The density of the soil was 1.25 g·cm^{-3}, which is slightly higher than that of natural fallow land. A slight increase in density may be associated with thermal destruction of organic matter, a decrease in the amount of root residues, and microbiological activity. In the 10–30 cm layers, the density decreased by 0.02–0.04 g·cm^{-3}, and the total porosity increased to 51.87%, indicating the absence of pyrogenic effects at depth. At a depth of 30–40 cm, the density increased again to 1.26 g·cm^{-3}, which is typical for the natural compaction of the lower horizons of chernozems. The average pore space was 1.03, indicating a slight decrease in aeration capacity, but without critical disturbances in the water-air regime. In general, pyrogenic degradation manifested itself mainly in the upper layer and did not cause significant changes in the deeper layers, confirming the local nature of the impact.

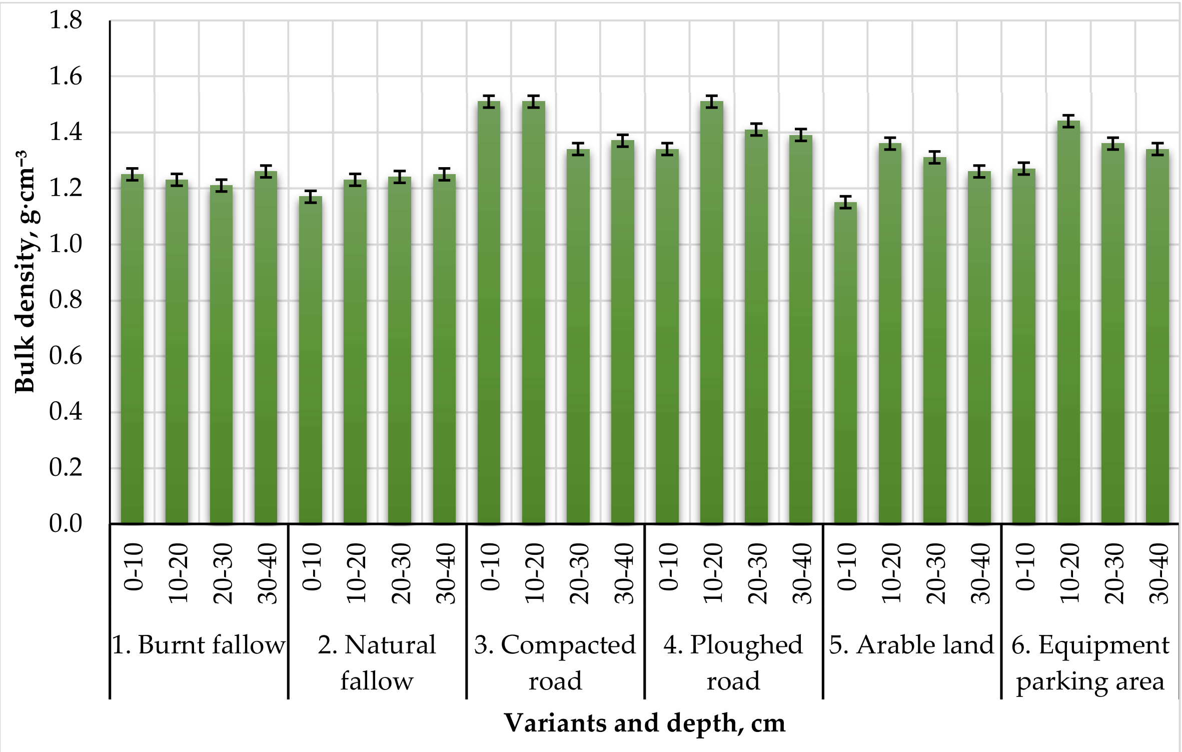

Figure 1. Change in the density of typical chernozem under the influence of military load, g·cm^{-3} ($LSD_{0.05}$ = 0.08)

The natural fallow was characterized by the lowest density in the upper layer of 0–10 cm — 1.17 g·cm^{-3}, accompanied by high overall porosity of up to 53.39%. This indicated a well-developed structure, stable condition, and active biota that maintains pore space. With depth, the density gradually increased to 1.25 g·cm^{-3} in the 30–40 cm layer, but the porosity remained consistently high (over 51%). The pore space in the upper layer reached 1.15, the highest value among all variants, indicating optimal conditions for gas exchange, infiltration, and root system development. Thus, natural loam is the reference state of typical chernozem, demonstrating maximum stability over time and the best physical properties.

The most intense compaction was observed on the section of the road where the density in the upper layers of 0–10 and 10–20 cm reached 1.51 g·cm^{-3}. This value exceeded the critical limits for chernozems, at which infiltration capacity and aeration are sharply reduced. The porosity in these layers was only slightly more than 40%, which was a sign of deep anthropogenic impact. At a depth of 20–30 cm, the density decreased to 1.34 g·cm^{-3}, and the porosity increased to 47.79%. However, these indicators still indicated existing disturbances in the profile. In the 30–40 cm layer, the density was 1.37 g·cm^{-3}, confirming the penetration of mechanical compaction to a considerable depth. These changes formed a compacted track with low water permeability and impaired gas exchange, which created a high risk of degradation processes, including surface runoff and erosion.

Surface tillage partially reduced the density in the 0–10 cm layer to 1.34 g·cm^{-3}, while porosity increased to 48.24% (Figure 2). However, in the 10–20 cm layer, the density increased again to 1.51 g·cm^{-3}, indicating that the compacted layer under the arable horizon remained intact. This is a typical situation where tillage only loosens the surface but does not eliminate deeper compaction. In the 20–40 cm layers, the density stabilized at 1.39–1.41 g·cm^{-3}, and the porosity at 45–46%. The average pore space was 0.83, which indicated restrictions on water and air regimes. Thus, surface cultivation does not eliminate the effects of technogenic compaction, but only shifts the problem to a depth of 10–20 cm, forming a secondary compacted horizon.

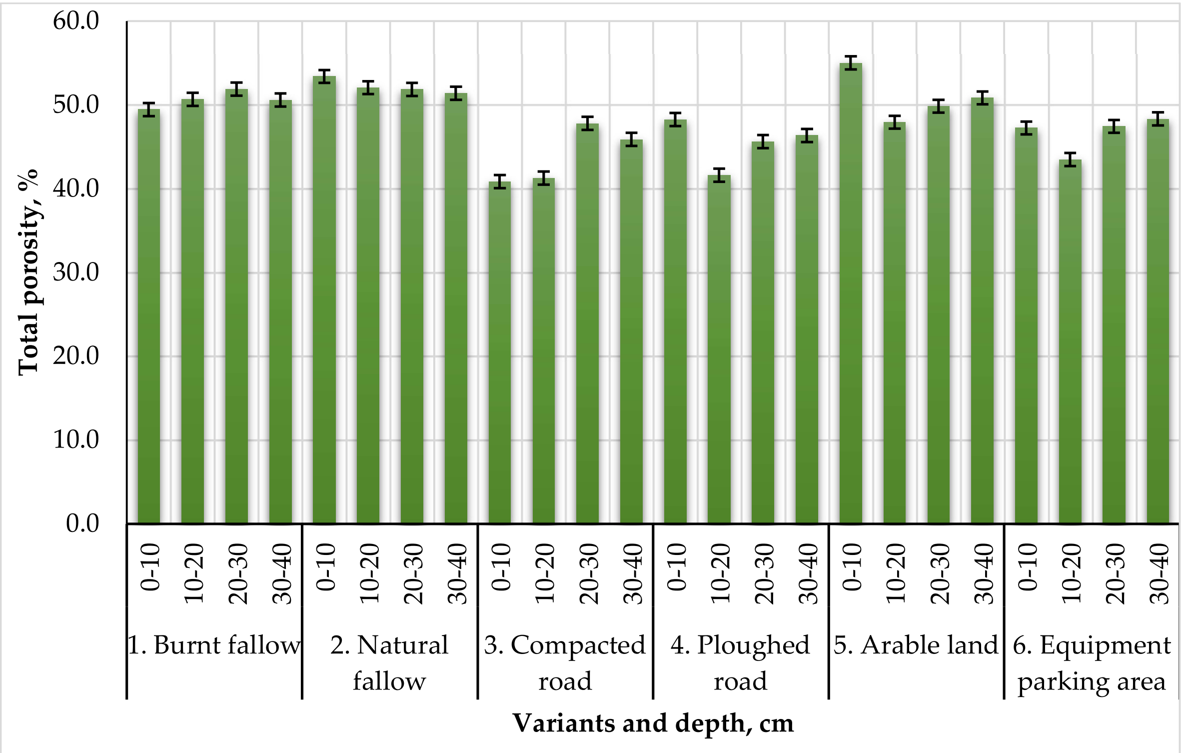

Figure 2. Change in the total porosity of typical chernozem under the influence of military load, % ($LSD_{0.05}$ = 3.60)

In the plowed variant, the top layer (0–10 cm) had the lowest density among the agrogenic variants—1.15 g·cm^{-3}, and the porosity reached 55.00%. This indicated the effectiveness of regular tillage in loosening the surface layer. However, at a depth of 10–20 cm, the density increased to

1.36 g·cm^{-3}, indicating the formation of a plow pan. In the 20–40 cm layers, the density decreased to 1.26–1.31 g·cm^{-3}, and the porosity increased by 2–3%. The volume of pores in the 20–30 cm layer was 8.84, which was the highest value among all variants and possibly indicated moisture accumulation in the lower part of the humus horizon. Thus, agrogenic use caused profile differentiation and the formation of a plow pan, which limited moisture availability for plants.

Table 1. Indicators of pore space and pore volume of typical chernozem after military loading

Variant	Depth, cm	Pore space	Pore volume, cm^3·cm^{-3}
1. Burnt fallow	0-10	0.98	5.56
	10-20	1.03	5.20
	20-30	1.08	4.87
	30-40	1.02	4.82
2. Natural fallow	0-10	1.15	4.58
	10-20	1.09	5.12
	20-30	1.08	5.23
	30-40	1.06	5.27
3. Compacted road	0-10	0.69	5.69
	10-20	0.70	6.28
	20-30	0.92	5.52
	30-40	0.85	4.14
4. Ploughed road	0-10	0.93	5.63
	10-20	0.71	6.37
	20-30	0.84	6.12
	30-40	0.86	6.33
5. Arable land	0-10	1.22	4.45
	10-20	0.92	6.03
	20-30	0.99	8.84
	30-40	1.03	6.44
6. Equipment parking area	0-10	0.90	4.73
	10-20	0.77	6.36
	20-30	0.90	5.78
	30-40	0.94	5.33
$LSD_{0.05}$		0.12	0.95

In the area where military equipment was temporarily stored, the density in the 0–10 cm layer was 1.27 g·cm^{-3}, which was close to the indicators for fallow land. However, at a depth of 10–20 cm, it rose sharply to 1.44 g·cm^{-3}, and porosity decreased to 43.47%. This indicated prolonged pressure from the weight of the equipment, which caused the formation of a compacted layer beneath the surface. In the 20–40 cm layers, the density decreased to 1.34–1.36 g·cm^{-3}, and the porosity was 47–48%. The pore space was 0.88, which may have indicated a decrease in biological activity, probably exacerbated by contamination with fuels and lubricants. This combination of mechanical pressure and possible chemical contamination created persistent disturbances that could persist for a long time and require special remediation measures.

Analysis of correlations between the main physical indicators of typical chernozems revealed a close interdependence between density, total porosity, and pore space. It was found that with an increase in bulk density, there was a marked decrease in total porosity (r equals -0.972; $p < 0.001$), which was characteristic of degraded and technologically disturbed soils. Pore space also showed a strong negative correlation with density (r equals -0.971; $p < 0.001$), indicating a deterioration in aeration properties and a potential decrease in biological activity. In contrast, solid phase density had weak or statistically insignificant correlations with other indicators (e.g., r equals -0.148; p equals 0.49 with total porosity), confirming its relative stability and dependence mainly on mineralogical composition rather than anthropogenic impact. Additionally, it was found that total porosity and pore space were closely positively correlated (r equals 0.997; $p < 0.001$), while their correlation with pore volume was moderate (r equals -0.338; p equals 0.110). The obtained correlation dependencies are consistent with the profile changes in indicators and confirm that it is the bulk density that is the most sensitive indicator of the physical degradation of typical chernozems under the influence of mechanical and pyrogenic loads.

Table 2. Correlation matrix of the dependence of physical indicators of typical chernozems under the influence of combat operations

Indicator	Soil density	Soil solid phase density	Total porosity	Pore space	Volume of pores
Soil density	1.0 (p=0.0000)	0.374 (p=0.0719)	-0.972 (p=0.0000)	-0.971 (p=0.0000)	0.437 (p=0.0327)
Soil solid phase density	0.374 (p=0.0719)	1.0 (p=0.0000)	-0.148 (p=0.4902)	-0.157 (p=0.4647)	0.504 (p=0.0121)
Total porosity	-0.972 (p=0.0000)	-0.148 (p=0.4902)	1.0 (p=0.0000)	0.997 (p=0.0000)	-0.338 (p=0.1065)
Pore space	-0.971 (p=0.0000)	-0.157 (p=0.4647)	0.997 (p=0.0000)	1.0 (p=0.0000)	-0.361 (p=0.0829)
Volume of pores	0.437 (p=0.0327)	0.504 (p=0.0121)	-0.338 (p=0.1065)	-0.361 (p=0.0829)	1.0 (p=0.0000)

The identified profile differences between natural, agrogenic, and technogenically disturbed areas, as well as the established correlations between density and porosity, were consistent with the results of a number of domestic and foreign studies. These studies also describe similar trends in compaction, reduced porosity, and deterioration of the water-air regime of soils under the influence of intensive use and technogenic load. This correspondence confirmed the importance of the data obtained and allowed them to be interpreted in the context of current ideas about the mechanisms of physical degradation of chernozems.

Physical degradation is one of the key manifestations of military impact on soil cover. It is particularly dangerous for agricultural land, as it leads to a deterioration in agrophysical properties, the formation of compacted areas where equipment is based, the creation of turning strips, and local areas with disturbed soil structure (Plisko et al., 2025). Studies have confirmed that the most intense changes occurred in the upper soil layers, especially within the arable horizon, where the density reached critical values. In road sections and equipment parking areas, the density in the 0–10 cm layer exceeded 1.43 $g \cdot cm^{-3}$, which corresponded to the formation of a compacted track with a depth of up to 10–12 cm (Plisko et al., 2023). Similar patterns have been described in international studies, where even a few passes of machinery, especially in wet soil, can cause significant compaction at depths of 10–30 cm (Alaoui and Diserens, 2011).

A comparison with literature data showed that the density of the arable layer can increase to 1.35–1.45 $g \cdot cm^{-3}$ after only 4–7 passes of the equipment (Medvedev, 2002). In cases of agrogenic use, such as arable land and plowed roads, a decrease in density was observed in the upper layer, demonstrating the effectiveness of surface cultivation. However, in deeper horizons of 30–40 cm, the density remained elevated at 1.33–1.41 $g \cdot cm^{-3}$, indicating insufficient depth of recultivation impact. This confirmed the negative effects of intensified agronomic practices, which can lead to excessive surface dispersion and deterioration of soil physical properties (Yakovenko et al., 2023).

In variants with pyrogenic influence, in particular on burnt fallow land, an increase in density was observed only in the upper layer, while deeper soil layers retained values close to natural ones. This confirmed the local nature of pyrogenic degradation, which did not penetrate deeper than 20 cm. Natural variants showed the lowest density values across the entire profile, which characterized the preserved profile structure and stable water permeability regime.

Military activity deserves special attention, as the movement of tracked vehicles can form deep compacted layers, which was confirmed by high density values at all depths studied (Reyes et al., 2005; Broomandi et al., 2020). According to Müller et al. (2021), the greatest compaction (from 1.2 to 1.5 $g \cdot cm^{-3}$) is formed in the surface layer of soil at a depth of 0–6 cm after just three passes of military vehicles. Even foot traffic can increase density by more than 30% compared to the control, accompanied by a decrease in water infiltration rate, a reduction in above-ground biomass, and an increased risk of erosion processes (Whitecotton et al., 2000). In the variants where military equipment was present, the density in the upper layer increased by 0.39 $g \cdot cm^{-3}$, and in the 10–20 cm layer — by 0.17 $g \cdot cm^{-3}$ compared to the natural state, which confirmed the formation of a compacted layer capable of significantly limiting the development of agricultural crops (Plisko et al., 2023).

It is known that an increase in soil compaction density negatively affects crop yields. According to the literature, compaction of chernozems above 1.45–1.50 $g \cdot cm^{-3}$ leads to a 10–15% reduction in wheat yield due to restricted root system development and reduced water permeability (Dudka et al., 2022). Similar results have been obtained for corn and soybeans, where excessive soil density reduces yield potential by deteriorating the physical properties of the profile (Gao et al., 2025; Ferreira et al.). Thus, the critical values of compaction density established by us have direct practical significance for predicting crop productivity in combat-affected areas (Table 3).

Table 3. Generalized dependence of wheat, corn, and soybean yields on soil density according to literature data (Ferreira et al., 2020; Dudka et al., 2022; Gao et al., 2025)

Soil density	Wheat	Maize	Soybean
1.20–1.25	4.5–5.0	9.0–9.5	2.8–3.0
1.40–1.45	3.8–4.2	7.5–8.0	2.4–2.6
>1.55	<3.5	<7.0	<2.2

In summary, it can be noted that soil density was a sensitive and reliable indicator of physical degradation, which allowed for a quantitative assessment of the impact of various types of stress—from agricultural to military—on the condition of chernozems. The results confirm the need for measures aimed at reducing soil bulk density and increasing its porosity. Such measures include deep loosening of compacted horizons, the use of organic fertilizers and green manure to improve soil structure, minimizing the movement of heavy equipment in the fields, and carrying out recultivation work on technogenically disturbed areas. The application of these practices will contribute to the restoration of the soil's water-air regime and increase its ecological stability in post-conflict landscapes.

4. Conclusions

The studies conducted made it possible to comprehensively assess the profile changes in the bulk density, porosity, and pore space parameters of typical chernozems under different land use conditions and anthropogenic loads. This reflected both surface and depth differences between natural, agrogenic, and technogenically disturbed areas and allowed for a quantitative characterization of the degree of physical changes in the soil profile. It was found that profile changes in density clearly reflect the intensity of the load: under natural conditions, it remained within the range of 1.17–1.25 $g \cdot cm^{-3}$, while in technogenically disturbed areas, it increased to 1.44–1.51 $g \cdot cm^{-3}$ in the upper horizons, indicating significant compaction and a decrease in pore volume.

Military use caused the most profound and persistent changes in the physical condition of the soil, with compaction to a depth of 30–40 cm and density values of up to 1.34 $g \cdot cm^{-3}$, confirming the formation of compacted layers and limiting vertical water movement. Agrogenic use resulted in a differentiated profile with a plow sole at a depth of 10–20 cm, where the density exceeded 1.36 $g \cdot cm^{-3}$ with a 7–10% reduction in porosity, which limited water permeability and contributed to moisture accumulation in the lower part of the humus horizon. Pyrogenic impact was local in nature and manifested itself mainly in the upper layer of 0–10 cm, where the density increased to 1.25 $g \cdot cm^{-3}$ with a decrease in pore space, while deeper horizons retained parameters close to natural ones.

Pore space indicators showed high sensitivity to different types of loading: total porosity exceeded 51–53% in natural conditions and decreased to 40–46% in technogenically disturbed areas, while pore space ranged from 0.69–0.93 in compacted areas to over 1.15 in natural areas, reflecting significant differences in the water-air regime. Correlation analysis confirmed a close interdependence between packing density and pore space parameters, in particular negative correlations between density and total porosity (r equals -0.972; $p < 0.001$) and pore space (r equals -0.971; $p < 0.001$), which demonstrated the systematic nature of changes in the profile and confirmed the possibility of using density as an integral indicator of the physical condition of the soil.

Values above 1.45–1.50 $g \cdot cm^{-3}$ in the upper horizons can be considered as thresholds for determining critical compaction requiring reclamation measures. To improve the physical condition of soils, it is advisable to use deep loosening, minimize the movement of heavy equipment, use organic fertilizers to improve structure, introduce crop rotations with crops that form a branched root system, and avoid tillage in waterlogged conditions. The results obtained are of practical importance for monitoring the condition of the soil profile and assessing the degree of anthropogenic impact, and the established ranges of density and porosity can be used to plan restoration work and develop methods for improving the physical condition of chernozems in post-conflict landscapes.

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