

Influence of anthropogenic factors on humus in Phaeozems of Ashotsk land cadastral district

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Abstract. The study was conducted on Phaeozems of the Ashotsk land cadastral region (ALCR), Republic of Armenia. Field investigations compared virgin and long-term cultivated soil variants. Total humus content was determined using the Tyurin method, and the qualitative composition of humus was analyzed according to the Kononova and Belchikova procedure. The results demonstrated that in the plough horizon of cultivated soils, the content and total stock of humic acids, fulvic acids, and non-hydrolyzable residue decreased by 18%, 15.6%, and 17%, respectively. Under prolonged agricultural use, both quantitative and qualitative humus characteristics changed considerably. Compared with virgin soils, total humus content declined by approximately 32%, while humic and fulvic acid fractions decreased by 16–18%. These findings confirm progressive deterioration of humus in cultivated Phaeozems and highlight the necessity of fertility restoration measures. Management practices that may be considered include the application of organic fertilizers (55–65 t ha⁻¹) combined with mineral fertilizers in prescribed doses (N90, P100, K60) and the implementation of minimum or zero tillage within adaptive landscape farming systems.

Key words: phaeozems, humus, humic acids, fulvic acids, non-hydrolyzable residue.

INTRODUCTION

According to the World Reference Base for Soil Resources (WRB), meadow-steppe soils of Armenia correspond to the Phaeozems reference group (FAO, 2015;

Gerasimova & Krasilnikov, 2024). The term Phaeozem derives from the Greek word *phaios* (dark) and the Russian word *zem* (earth), reflecting the dark coloration and relatively high organic matter content of these soils. Phaeozems typically develop under herbaceous vegetation in temperate continental climates and are widely distributed in Eurasian steppe and forest-steppe regions.

In different national classification systems, analogous soils have been described as brunizems (Argentina, France), dark gray forest soils, leached and podzolized chernozems (former USSR), Parabraunerde-Chernozem (Germany), and Udolls/Albolls in the United States classification systems. Despite terminological differences, these soils share common pedogenetic features related to humus accumulation under grass-dominated vegetation and base-rich parent materials.

Recent studies in Armenia have highlighted the increasing importance of soil monitoring and sustainable land management under anthropogenic pressure. Geospatial assessments have demonstrated significant spatiotemporal variability of soil properties, including degradation processes in saline-alkaline soils, emphasizing the need for integrated soil evaluation approaches (Markosyan et al., 2025a). Furthermore, fertilization studies conducted under varying agro-climatic conditions have confirmed that rational nutrient management plays a crucial role in maintaining soil productivity and improving crop quality (Markosyan et al., 2025b).

Humus plays a central role in soil fertility, influencing aggregation, water retention, nutrient buffering capacity, and biological activity. The content and qualitative composition of humic substances are closely linked to soil genesis and environmental conditions. Anthropogenic impacts – particularly continuous cultivation, improper fertilization, and unsystematic land management – disturb soil equilibrium, accelerate mineralization processes, and alter the structure of soil organic matter (Kumada, 1987; Quideau et al., 2000; Lai, 2004; Ogle et al., 2005; Haile-Mariam et al., 2008; Asano & Wagai, 2015; Baveye & Wander, 2019).

Although numerous studies have addressed humus dynamics in agricultural soils, **comparative evaluations of both quantitative and fractional composition of humus in mountain Phaeozems under long-term cultivation remain limited**, particularly under relatively homogeneous agro-ecological conditions. In small but geomorphologically uniform regions, such as the Ashotsk land cadastral region (ALCR), even a limited number of well-characterized soil profiles can provide representative insight into soil-forming processes and anthropogenic transformation trends. In the ALCR, located within the mid-mountain belt of Armenia, the dynamics of humus content and its fractional composition under long-term agricultural use have not been sufficiently quantified and interpreted in an integrated manner. Understanding these changes is essential not only for regional soil assessment but also for improving the conceptual understanding of humus transformation processes in mountain Phaeozems subjected to continuous cultivation.

Therefore, the objective of this study was to evaluate the quantitative and qualitative changes in humus composition of Phaeozem soils in the Ashotsk land cadastral region of the Republic of Armenia under long-term anthropogenic impact, with particular emphasis on the transformation of humus fractions and their implications for soil fertility.

MATERIALS AND METHODS

Study area

The study was conducted in the Ashotsk land cadastral region (ALCR) of the Republic of Armenia, located within the mid-mountain belt at elevations of 2200–2700 m above sea level. The investigated soils belong to the Phaeozem reference group (FAO, 2015; Gerasimova & Krasilnikov, 2024) and have undergone long-term agricultural use.

The region is characterized by a temperate continental climate, pronounced natural drainage, meadow-steppe vegetation, and base-rich volcanic parent materials (andesites, basalts, granodiorites). The relatively homogeneous geomorphological, climatic, and vegetation conditions of the region allow the identification of representative soil profiles reflecting dominant soil-forming processes.

Three representative soil profiles were selected, including one virgin site and two long-term arable sites. Although the number of profiles is limited, the selected sites are considered representative of the prevailing soil conditions within the ALCR, enabling a comparative evaluation of anthropogenic effects under relatively uniform environmental conditions.



Figure 1. Location of soil profiles in the Republic of Armenia.

The geographic location of the investigated soil profiles within the Republic of Armenia is presented in Fig. 1.

A detailed spatial distribution of the sampling sites within the Ashotsk land cadastral region (ALCR) is shown in Fig. 2.



Figure 2. Detailed location of soil sections in the Ashotsk land cadastral region (ALCR).

Geographic coordinates and altitudinal characteristics of the soil profiles are summarized in Table 1.

Table 1. Geographic coordinates and altitudinal characteristics of soil sampling sites in the Ashotsk land cadastral region (ALCR), Republic of Armenia

Section	Land use type	Altitude (meters above sea level)	Latitude (N)	Longitude (E)
1	Virgin soil	2,404	41°06'31.65"	43°53'14.40"
2	Arable soil	2,411	41°07'23.36"	43°53'18.20"
3	Arable soil	2,241	41°07'25.04"	43°52'02.76"

Soil sampling and field investigations

Soil pits were excavated to the depth of the parent material. On loose substrates, excavation reached approximately 1.0 m; on dense substrates, excavation continued until the parent material was exposed.

Samples were collected from genetic horizons (A, B₁, B₂). Air-dried samples were crushed and sieved (1.0 mm mesh). The 'key site' method was applied for representative selection (Arinushkina, 1970; Aleksandrova & Naydenova, 1986), which is widely used in classical soil science for identifying representative soil profiles under homogeneous environmental conditions.

Determination of humus content (Tyurin Method)

Total organic carbon was determined using the wet oxidation method of I.V. Tyurin, involving potassium dichromate oxidation in sulfuric acid medium, followed by titration with Mohr's salt.

Humus content was calculated using:

$$\text{Humus (\%)} = \%C \times 1.724$$

All analyses were performed in duplicate. The Tyurin method is a widely accepted classical approach in soil science and remains extensively used for comparative studies of soil organic matter.

Group and fractional composition of humus

The qualitative composition of humus was determined using the accelerated extraction method of Kononova and Belchikova (Kononova & Belchikova, 1961), based on sequential extraction with sodium pyrophosphate and sodium hydroxide (pH 12–13).

Humus was fractionated into the following components:

- Humic acids (HA)
- Fulvic acids (FA)
- Non-hydrolyzable residue

(humins).

Humic acids were further subdivided according to their binding strength with mineral components (HA-1, HA-2, HA-3 fractions). The

HA/FA ratio was calculated as a diagnostic indicator of humus type and transformation processes.

Although modern analytical techniques (e.g., spectroscopic and molecular approaches) provide more detailed characterization of soil organic matter, the applied method remains a standard and comparable approach widely used in pedological studies, enabling consistency with previous research.

Interpretation of the HA/FA ratio followed classical pedological criteria (Table 2).

Determination of total nitrogen

Total nitrogen was estimated based on humus content, assuming that nitrogen constitutes approximately 5% of total humus in mineral soils. This approach represents an indirect estimation and is used to provide a general indication of nitrogen dynamics. The limitations of this method should be considered when interpreting C:N ratios.

Laboratory conditions

Laboratory analyses were performed at the H. Petrosyan Scientific Center of Soil Science, Agrochemistry and Melioration of the Armenian National Agrarian University, following standard soil science procedures.

RESULTS AND DISCUSSION

Humus content and profile distribution in virgin soils

Quantitative and qualitative analysis of humus in virgin Phaeozem soils revealed substantial accumulation of organic matter in the upper horizons (Table 3). In the sod-humus horizon (Ad, 0–3 cm), humus content reached 13.4%, progressively decreasing with depth to 1.3% in the B₂ horizon (31–47 cm). A similar vertical decline was observed for total nitrogen and organic carbon, reflecting typical stratification of organic matter in undisturbed soils.

Table 2. Interpretation of HA/FA ratio for humus type classification

HA/FA ratio	Humus type	Characteristic features
> 2.0	Humate	Typical of chernozems; highly stable humus
1.0–2.0	Fulvate-humate	Balanced humus state; dark gray forest soils
0.5–1.0	Humate-fulvate	Initial degradation or podzolization trends
< 0.5	Fulvate	Podzolic soils; low fertility

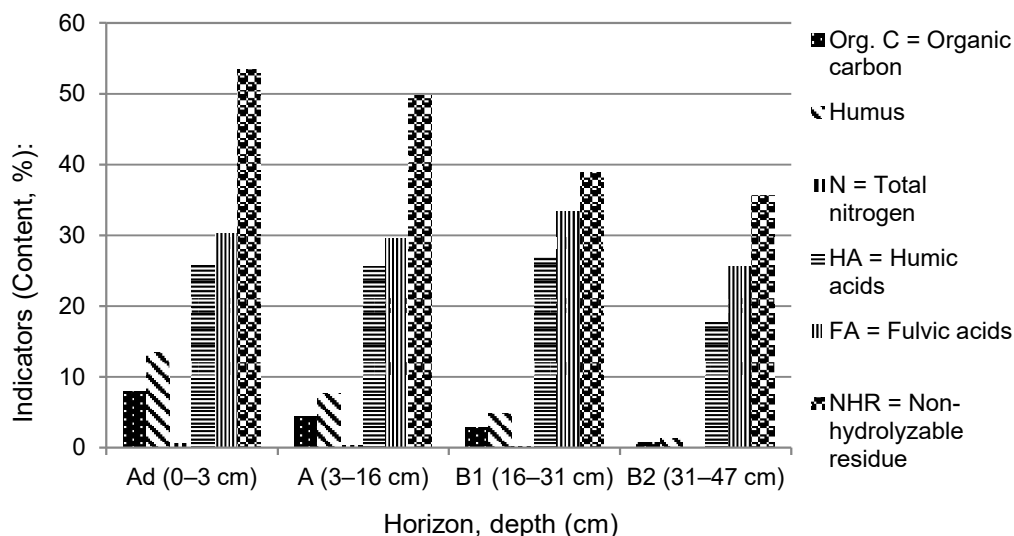
Table 3. Humus content and qualitative composition in virgin Phaeozem soils (ALCR)

Horizon	Depth (cm)	Organic C (%)	Humus (%)	Total N (%)	Humic acids (HA, %)	Fulvic acids (FA, %)	Non-hydrolyzable residue (NHR, %)
Ad	0–3	7.93	13.4	0.67	25.9	30.2	53.4
A	3–16	4.47	7.7	0.39	25.6	29.5	49.8
B ₁	16–31	2.87	4.9	0.25	26.9	33.4	38.9
B ₂	31–47	0.78	1.3	0.07	17.7	25.6	35.7

The total content of humic acids (HA) in the humus horizon varied between 25.6% and 25.9%, while fulvic acids (FA) ranged from 29.5% to 30.2%. The content of non-hydrolyzable residue (NHR) reached 53.4% in the uppermost horizon (Table 3). The HA/FA ratio ranged between 0.86 and 0.87, corresponding to a humate-fulvate type according to the classification presented in Table 2. This indicates a relatively balanced humus system with active transformation processes typical for mountain Phaeozems under meadow-steppe vegetation.

The C:N ratio in virgin soils varied from 11.1 to 11.8, reflecting relatively stable organic matter composition. With increasing depth, both humus and nitrogen contents declined, leading to a narrower C:N ratio (6.9–7.9), which suggests intensified mineralization processes and reduced stabilization of soil organic matter.

The vertical distribution of humus content and its fractional composition is illustrated in Fig. 3.

**Figure 3.** Distribution of humus content and fractional composition (organic C, total N, HA, FA, and NHR) across genetic horizons in virgin Phaeozem soil (ALCR).

Humus composition in arable soils (Profile 2)

Long-term cultivation altered both the quantitative and fractional composition of humus (Table 4). In the plough horizon (Ap, 0–19 cm), humus content decreased to 9.2%, compared with 13.4% in virgin soils. The content of humic acids declined to 20.4%, while fulvic acids decreased to 26.9%, and non-hydrolyzable residue to 44.7%.

Table 4. Humus content and qualitative composition in arable Phaeozem soil (Profile 2, ALCR)

Horizon	Depth (cm)	Organic C (%)	Humus (%)	Total N (%)	Humic acids (HA, %)	Fulvic acids (FA, %)	Non-hydrolyzable residue (NHR, %)
Ap	0–19	5.42	9.2	0.46	20.4	26.9	44.7
B	19–36	2.15	3.7	0.19	24.5	24.9	37.3
B ₂	36–54	0.60	1.0	0.05	18.9	31.6	34.6

These changes indicate enhanced mineralization and redistribution of organic matter under cultivation. The relative increase in hydrolyzable humus fractions in subsurface horizons is associated with downward translocation of mobile humic components, particularly HA-2 fractions.

Within the fractional composition, HA-1 predominates in upper horizons, while the proportion of HA-2 increases with depth, reflecting vertical differentiation of humus fractions. The fraction of tightly bound HA-3 represents the smallest share in the carbon balance of humic acids, indicating limited stabilization of humus through organo-mineral associations.

Humic acids associated with calcium do not exceed 4% of total soil carbon in upper horizons, suggesting relatively weak base stabilization. The decrease of HA-1 content with depth corresponds to the reduction of root biomass and organic inputs (Fig. 4).

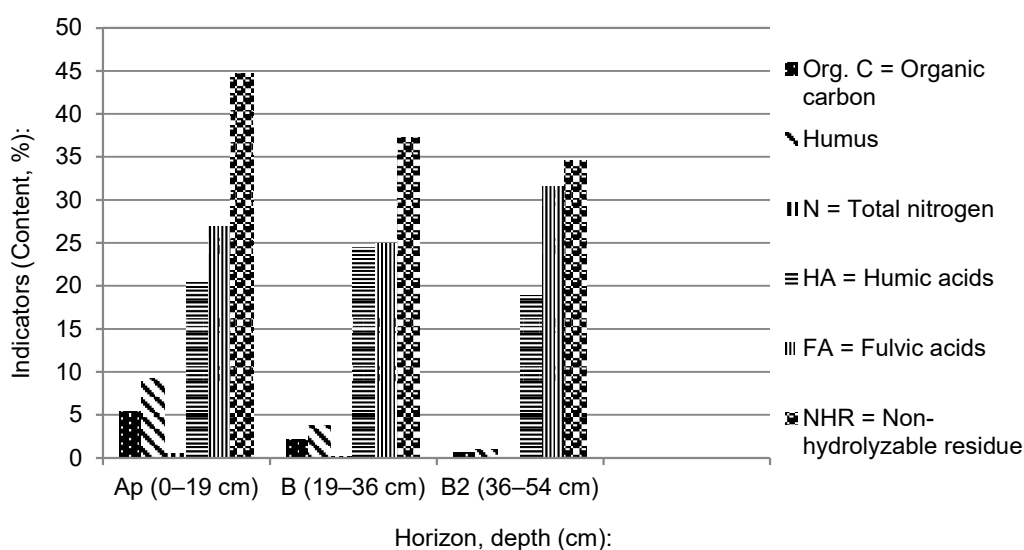


Figure 4. Distribution of humus content and fractional composition (organic C, total N, HA, FA, and NHR) across genetic horizons in arable Phaeozem soil (Profile 2, ALCR).

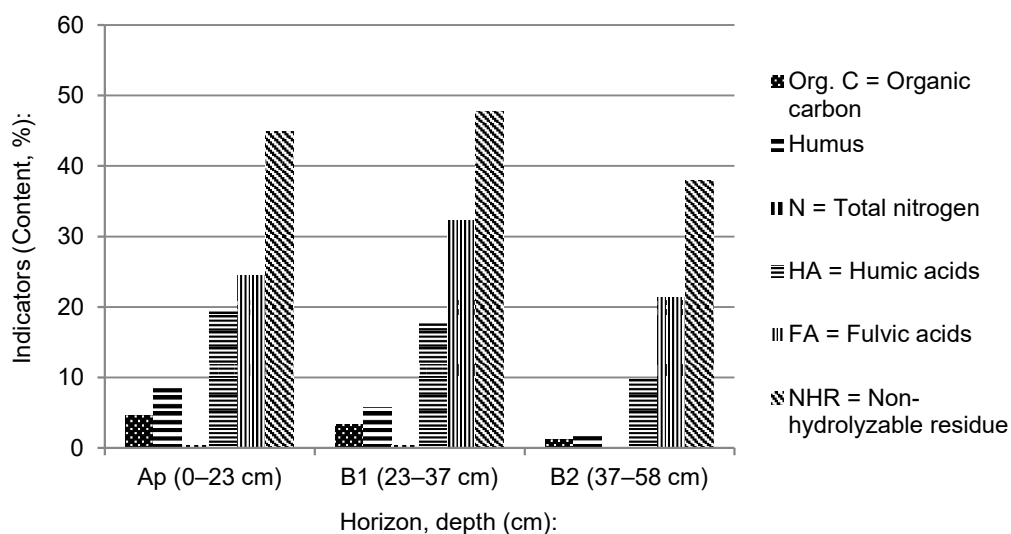
Humus composition in cultivated soils (Profile 3)

Further deterioration of humus composition was observed in cultivated soil variants (Table 5). In the Ap horizon (0–23 cm), humus content ranged from 8.9% to 9.2%, representing a reduction of approximately 32% compared with virgin soils. Decreases were observed across all major humus fractions, including HA, FA, and non-hydrolyzable residue.

Table 5. Humus content and qualitative composition in cultivated Phaeozem soil (Profile 3, ALCR)

Horizon	Depth (cm)	Organic C (%)	Humus (%)	Total N (%)	Humic acids (HA, %)	Fulvic acids (FA, %)	Non-hydrolyzable residue (NHR, %)
Ap	0–23	4.60	8.9	0.450	19.6	24.5	44.9
B ₁	23–37	3.36	5.8	0.290	17.9	32.3	47.8
B ₂	37–58	1.22	2.1	0.105	9.8	21.3	37.9

Phaeozem soils under cultivation exhibited a lack of synchrony between total humus accumulation and the proportion of humic acids. Although total humus reserves in the upper soil layers remain relatively high, the proportion of the most agronomically valuable fractions – particularly humic acids – was reduced.

**Figure 5.** Distribution of humus content and fractional composition (organic C, total N, HA, FA, and NHR) across genetic horizons in cultivated Phaeozem soil (Profile 3, ALCR).

Graphical analysis indicated that HA content in tilled horizons decreased by 5.6–6.4% compared to virgin soils. Similar trends were observed for FA (3.3–5.7% reduction) and non-hydrolyzable residue (approximately 8.5% decrease), reflecting progressive degradation of humus quality under long-term anthropogenic pressure (Vašková et al., 2023, Tiwari et al., 2023).

The reduction of humus and humic substances in cultivated Phaeozems leads to a decline in soil fertility. This is primarily due to the weakening of structural aggregation, as humus plays a key role in binding soil particles into stable aggregates. The breakdown of soil structure negatively affects aeration, thermal regime, and water circulation, ultimately reducing soil productivity and crop yield potential.

Implications for soil fertility

Long-term and unsystematic agricultural use has resulted in measurable degradation of both quantitative and qualitative humus parameters in mountain Phaeozems. The observed decrease in total humus content, reduction in humic acids, narrowing of the C:N ratio, and shifts in the HA/FA balance collectively indicate ongoing degradation trends (Kroyan et al., 2024).

Morphologically, arable soils exhibit slightly increased humus horizon thickness (3–7 cm), likely due to plough mixing. However, cultivated soils display lighter coloration and a finer lumpy-granular structure compared to virgin variants, reflecting qualitative degradation of the humus complex (Nardi et al., 2024).

The soils are characterized by a slightly acidic to neutral reaction (pH 6.1–7.0), with upper horizons showing weak acidity due to leaching processes, while deeper horizons approach neutrality as a result of carbonate accumulation.

To improve soil fertility and mitigate further degradation, management practices such as the application of organic fertilizers (55–65 t ha⁻¹) combined with balanced mineral fertilization (N90, P100, K60), increased inclusion of perennial grasses in crop rotations, and the adoption of reduced or minimum tillage systems may be considered. These approaches are consistent with established soil management principles and are expected to contribute to long-term stabilization of humus and improvement of soil resilience.

The observed trends in humus transformation are consistent with findings reported for other temperate steppe and forest–steppe soils, where continuous cultivation leads to enhanced mineralization and structural destabilization of soil organic matter (Okorkov, 2017; Bazhina et al., 2019; Zavarzin et al., 2019; Kogut et al., 2021; Lukin et al., 2021; Zavyalova et al., 2021; Pinaeva & Akmanava, 2022; Khalate et al., 2023).

The decrease in non-hydrolyzable residue and labile humic fractions observed in the present study corresponds to patterns reported in long-term cultivated soils of arid and semi-arid regions, where continuous ploughing enhances oxidation of organic matter and reduces humus stability (El-Metwally et al., 2014; Bazhina et al., 2019). According to classical pedological concepts (Zakharov, 1934), sustained agricultural pressure may gradually transform humate-fulvate systems toward less stable forms, particularly under insufficient organic input.

The predominance of fulvic acids and relatively low HA/FA ratios recorded in the studied profiles align with findings reported for intensively managed Phaeozems and related soils in Northern and Eastern Europe (Kõlli & Ellermae, 2003; Kuht et al., 2023). Comparable structural characteristics of humic substances, including variations detected through spectroscopic analysis, have also been described by Giovanela et al. (2010), confirming that qualitative changes in humus fractions serve as sensitive indicators of anthropogenic impact.

Furthermore, the functional role of soil organic matter in maintaining structural stability and long-term fertility has been widely emphasized in sustainable agriculture frameworks (Kwiatkowska-Malina, 2018). The present findings therefore support the concept that maintaining balanced humus fractions is essential for ecological resilience and productivity of mountain Phaeozems under cultivation.

CONCLUSIONS

Phaeozems of the Ashotsk land cadastral region are characterized by well-drained conditions, continental climatic features, meadow-steppe vegetation, and enrichment of parent materials with base-forming elements.

These soils exhibit a relatively high degree of humification, stable structural aggregation, slightly acidic to neutral reaction, moderate absorption capacity, and considerable base saturation.

Humus formation throughout the soil profile occurs predominantly through fulvic acids, reflecting active transformation processes of organic matter under mountain environmental conditions.

In the sod-humus horizon, virgin soils showed higher humus content compared with cultivated variants. Long-term agricultural use was associated with an approximate 32% reduction in total humus content, accompanied by decreases in humic acids, fulvic acids, and non-hydrolyzable residue.

Although total humus reserves remain relatively high in upper horizons, the proportion of the most agronomically valuable fractions – particularly humic acids – appears comparatively lower under cultivation.

The results indicate that long-term agricultural use contributes to gradual changes in both the quantity and quality of humus in mountain Phaeozems.

Sustainable management of these soils may benefit from the implementation of soil-conserving agricultural practices, including balanced fertilization, improved crop rotation systems, and measures aimed at maintaining soil organic matter. Such approaches are expected to support long-term soil fertility and ecological stability.

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