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Research Article

# Effect of different land uses on some physicochemical and micromorphological properties of calcareous soils in East Azerbaijan Province, northwest of Iran

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**ABSTRACT-** Vegetation is one of the active pedogenic factors, although its influence on soil micromorphological properties has received relatively little attention. Therefore, the present study aimed to evaluate the effects of different land uses on selected chemical and physical soil properties and to investigate the resulting changes using micromorphological analyses in the Alkhalaj Dam area of East Azerbaijan Province, northwest of Iran. For this purpose, surface soil samples (0–30 cm) were collected from four different land uses—wheat, alfalfa, rangeland, and fallow—within plateau physiography and were subjected to physical, chemical, and micromorphological analyses. The results showed that soil texture remained unchanged across all land uses, except under wheat cultivation. Organic carbon, nitrogen, phosphorus, and potassium contents were highest in fallow and rangeland land uses and lowest in wheat land use. Calcium carbonate equivalent exhibited the highest values in fallow and wheat land uses, while the lowest values were observed in rangeland. Micromorphological observations indicated that voids in rangeland and fallow soils exhibited a much higher degree of development than those in agricultural land uses, with large voids occurring to a very large extent in rangeland and fallow soils. However, with the conversion of land use to agriculture, the abundance of coarse packing voids was greatly reduced and platy voids were formed. Overall, the results demonstrated that vegetation primarily influences soil microstructure and void characteristics and, consequently, soil physical properties. This study highlights the importance of conservation-oriented management practices to prevent soil degradation resulting from unconventional land-use changes.

## INTRODUCTION

Understanding the effects of land use on the quality of different soil types is essential for maintaining and improving soil productivity within sustainable agricultural systems (Azadi and Shakeri, 2020). Soil quality largely depends on the way soils respond to different land uses and management practices, as many soil properties, and consequently soil production capacity, can be improved through appropriate land-use planning and management strategies (Lizaga et al., 2019). Assessing soil quality is therefore crucial for informed decision-making aimed at sustaining high productivity and preventing soil degradation (Teng et al., 2024). Soil degradation commonly occurs following changes in land use and vegetation cover and represents a widespread environmental problem that can alter soil structure and, consequently, soil pore systems (Azadi et al., 2024). Changes in land use and management practices can significantly influence soil properties and overall soil quality, thereby affecting plant growth patterns and their surrounding environment. In particular, soil management and land-use alterations can modify processes such as leaching, oxidation, and mineralization, ultimately leading to the changes in soil quality and posing a serious threat to soil systems (Bekele, 2018). The study of soil micromorphology is an emerging field within soil science that has attracted considerable attention in recent years (Longhi et al., 2021). This approach employs image-processing techniques to quantitatively analyze pore size, pore abundance, and soil pedofeatures in thin sections. Changes in micromorphological characteristics provide valuable insights into relationships among soil development, environmental conditions, and the impacts of human activities on soil structure (Skvortsova and Kalinina, 2004; Perilla-Castillo et al., 2023).

Stoops (2003) emphasized the role of vegetation in shaping soil micromorphology, identifying it as a key

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indicator in pedological studies and an important tool for evaluating soil formation, classification, and management. Similarly, Lima et al. (2006) described micromorphology as a method for examining undisturbed soil samples using microscopic and, in some cases, advanced microscopic techniques to identify soil constituents and interpret their interactions across spatial and temporal scales. Environmental conditions, including land use, can influence micromorphological properties such as void types, microstructure, b-fabric, and the morphology of clay and iron coatings by altering soil physical and chemical properties (Wielemaker and Lansu, 1991). In structured soils, granules and porous grains tend to form spheroidal, elongated, and interconnected voids, whereas pores between blocky or platy aggregates are typically planar. The presence of massive structures or platy pores oriented parallel to the soil surface is commonly used as an indicator of soil compaction (Khormali et al., 2009). Soil fauna contribute to the formation of three main types of voids: channels, chambers, and modified voids. In micromorphological studies of calcareous soils, Abbaslou et al. (2013) reported that lenticular and irregular gypsum crystals exhibit very poor development under conditions of low rainfall, high evaporation, and elevated salinity. Kaewmano et al. (2010), in their study of the Natraqualfs great group in Thailand, observed that clay accumulation in subsurface horizons and the accumulation of soluble salts in both surface and subsurface horizons are indicative of argillic and natric horizons, respectively. These researchers attributed the increase in clay particles at deeper soil layers, where clay coatings are clearly visible, to clay leaching driven by high soil reaction (pH) and the hydrolysis of sodium carbonate (Abtahi, 1977).

Preventing the degradation and destruction of soil resources and ensuring their protection represent one of the most important responsibilities of the present generation toward future generations, a goal that can only be achieved through proper planning and sustainable utilization of soil resources. Improper exploitation of natural, God-given resources and inappropriate management practices lead to the degradation of natural systems and, consequently, a decline in production potential. To prevent environmental degradation and maintain soil productivity, the adoption of appropriate management strategies is essential. Human-induced changes have significantly influenced soil evolution (Shamsi Mahmoodabadi and Khormali, 2011), and increasing land-use changes have resulted in soil compaction and alterations in soil chemical properties. The direct and indirect consequences of land-use change, particularly the conversion of rangelands to agricultural lands, include the destruction of surface soil cover, intensified water and wind erosion, and the depletion of soil nutrients.

Land-use changes affect not only the physical, chemical, and morphological properties of soils but also their biological and other functional characteristics. Studying the effects of land-use change on the full range of soil properties can therefore provide valuable information for effective land management and decision-making (Azadi and Shakeri, 2020). In recent years, population growth has accelerated land-use changes, particularly the conversion of rangelands into agricultural lands. Despite this trend, research addressing the impacts of different land uses on soil properties, especially micromorphological characteristics, remains limited, restricting our understanding of these processes. Consequently, the present study not only examines the influence of various land uses on selected physicochemical soil properties but also investigates their effects on soil micromorphological attributes. Specifically, differences between rangeland and agricultural land uses are evaluated and compared.

This comprehensive approach provides valuable insights into micromorphological and physicochemical soil characteristics, with practical implications for improving land management and formulating effective conservation recommendations. The study seeks to address whether different land uses influence key physicochemical properties, such as Organic carbon (OC), which directly affects crop production, as well as micromorphological features, including soil compaction, void infilling, and soil fabric. Accordingly, the present study aims to evaluate the effects of different land uses on selected chemical and physical soil properties and to assess associated changes through micromorphological analyses in the Alkhalaj Dam area of East Azerbaijan Province, northwest of Iran.

## MATERIALS AND METHODS

### *Study area description*

This study was conducted at the Tikmehdash Research Station, located approximately 75 km southeast of Tabriz, at 45°37′ north latitude and 55°45′ east longitude, with elevations ranging from 1800 to 2000 m above sea level (Fig. 1). The study area has a semi-arid climate characterized by mild summers and cold winters. The absolute minimum winter temperature reaches −25 °C, while the absolute maximum summer temperature reaches up to 32 °C. The mean annual rainfall over the past ten years is 386 mm. The soil moisture and temperature regimes of the region are classified as arid and mesic, respectively.

From a physiographic perspective, much of the study area is associated with mountainous terrain as well as low and high plateaus of the Morgali Mountains. Most of the area has slopes ranging from 4% to 13%, while gentler slopes of 0% to 2% occur at valleys and hilltops. Soil classification in the study area indicates the presence of two soil orders: Entisols and Inceptisols.

### *Field sampling and physical, chemical, and micromorphological analyses*

To investigate the effects of different land uses on soil physicochemical and micromorphological properties, surface soil samples (0–30 cm) were collected as both disturbed and undisturbed samples from four land-use types, i.e., wheat, alfalfa, rangeland, and fallow, within plateau physiography. The wheat and alfalfa lands had originally been rangelands that were later converted to agricultural use. Undisturbed samples were collected for micromorphological analysis. Physicochemical analyses included the determination of soil texture using the hydrometer method (Gee and Bauder, 1986), electrical conductivity (EC) according to Bower et al. (1952), soil pH measured in a 1:5 soil-to-distilled water suspension (Thomas, 1996), OC determined by the Walkley and Black method (1996) as modified by Nelson and Sommers (1996), available phosphorus measured via the Watanabe and Olsen method (1965), total nitrogen determined by the Kjeldahl method (Jones, 2001), calcium carbonate equivalent (CCE) measured by the volumetric calcimeter method (Akrawi, 2018), and potassium content according to Helmke and Sparks (1996).

For micromorphological studies, undisturbed soil samples were collected in Kubiena boxes in rangelands of wheat, alfalfa, and fallow. The samples, obtained either in galvanized molds (Kubiena boxes) or as intact clods, were transported to the laboratory and air-dried for one month (Fitzpatrick, 1989). The dried samples were then impregnated with a mixture of polyester resin and acetone at a 9:1 ratio (900 mL resin and 100 mL acetone), along with 12 drops of cobalt hardener and a catalyst (stearic acid), under an 80 kPa vacuum in a desiccator. The samples were subsequently cured under vacuum conditions and allowed to polymerize at laboratory temperature (Murphy, 1986; Stoops, 2003). After complete polymerization, the impregnated samples were cut and mounted onto glass slides. Abrasion was performed using grinding disks, and sample thickness was reduced to 25–30 µm using carborundum powders with 220, 400, and 800 mesh grits (Murphy, 1986). The prepared thin sections were then examined and imaged using a polarizing microscope under plane-polarized light (PPL) and cross-polarized light (XPL). As a result, micromorphological features were described and interpreted according to the terminology proposed by Stoops (Bullock et al., 1985; Stoops, 2003).

## RESULTS AND DISCUSSION

*Effect of land uses on selected soil physical and chemical properties*

In the studied soils, the major pedogenic factors were relatively similar, with the exception of vegetation, as the sites shared the same climatic conditions, parent materials, and relief, and the region experienced long-term crop cultivation. The results of the physical and chemical analyses of the soil samples are presented in Table 1 and Table 2. According to these results, soil texture remained unchanged under alfalfa, rangeland, and fallow land uses. In contrast, sand content increased under wheat cultivation, resulting in a change in soil texture to sandy loam. Since wheat cultivation involves annual plowing and other agricultural operations, clay particles are likely washed from the surface horizon and translocated to lower horizons. Additionally, a portion of the clay in the surface horizon may be removed by runoff, leading to clay depletion.

As shown in Table 2, the highest OC contents were observed in fallow and rangeland land uses, whereas wheat land use exhibited the lowest OC content. This pattern suggests that agricultural operations following the conversion of rangeland to cropland have contributed to a decline in soil OC. Six et al. (2000) reported that continuous cultivation is the most important factor accelerating OC reduction in agricultural lands, as plowing enhances the decomposition of soil OC. Velayutham (2000) showed how understanding qualitative and quantitative characteristics of soil OC is essential for maintaining soil quality and productivity. Similarly, Korkanc et al. (2008) demonstrated that tillage operations reduce soil OC levels, and Shashikumar et al. (2023) reported that land-use change from rangeland to agricultural land decreases soil OC and contributes to soil

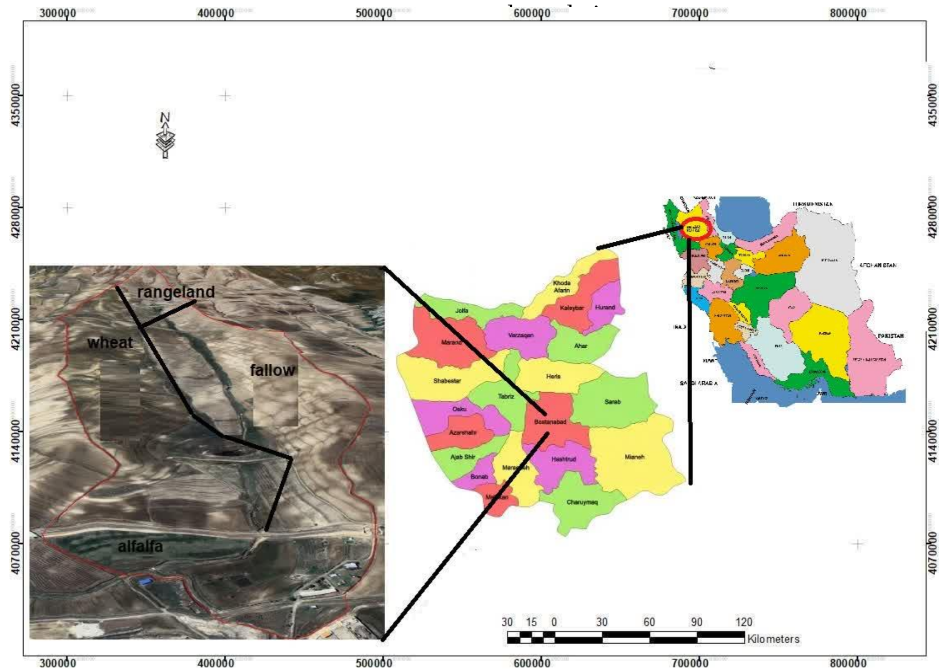


**Fig. 1.** Location of the studied area.

The highest total soil nitrogen content was observed in fallow and rangeland land uses, whereas the lowest value occurred under wheat cultivation (Table 2). Similar to OC, land-use change from rangeland to disturbed and cultivated land resulted in a reduction in total soil nitrogen. The adverse effects of non-normative tillage practices on soil structure and permeability increase surface runoff following land-use change. The greater susceptibility of agricultural lands to erosion contributes to reductions in soil OC, as runoff removes a substantial portion of soluble OC through erosion processes. Moreover, tillage mixes subsurface soil layers, which typically contain lower OC, with surface layers that originally have higher OC contents, leading to a net decline in surface soil OC compared to its undisturbed state. Each year, significant amounts of nitrogen from the surface layer are lost from the system along with sediment during erosion events.

Another major factor contributing to nitrogen depletion is the removal of natural vegetation during the conversion of forest and rangeland to agricultural land. Vegetation removal and surface soil disturbance accelerate biological decomposition of OC, increase nitrogen mineralization, and ultimately reduce total soil nitrogen by altering soil moisture and temperature regimes. Additionally, the decline in nitrogen content under agricultural land use may be associated with increased CCE, which reduces soil fertility. Sanchez-Marañón (2002) reported that conversion of Mediterranean rangelands to rainfed agricultural land resulted in a 65% reduction in total soil nitrogen. Boostani et al. (2019) found that forest and pasture land uses had significantly higher cation exchange capacity, organic matter content, and pH compared with orchard land use. In their study, soil OC ranged from 0.9% to 1.94% and was higher under fallow and forest land uses, which they attributed to differences in soil mineral structure. They further explained that soil disturbance caused by changes in temperature, moisture, and aeration during cultivation and fallowing accelerates organic matter decomposition.

Shakeri and Azadi (2022) similarly attributed variations in nitrogen content under different land uses to erosion, emphasizing that substantial amounts of soil OC and total nitrogen are removed along with colloidal particles in runoff. In addition, tillage enhances nitrogen mineralization, further reducing soil nitrogen reserves. pH, which reflects soil acidity or alkalinity, also varied among land uses. Soil analyses indicated that the highest pH values occurred in fallow and wheat land uses, while the lowest pH was observed under alfalfa cultivation (Table 2). One possible explanation for the higher pH in fallow and wheat soils is the presence of calcareous minerals, which increase calcium carbonate content. Disturbance of the soil profile during agricultural operations can bring calcareous materials to the surface and reduce soil OC, both of which contribute to increased soil pH under agricultural land use. Korkanc et al. (2008) reported that tillage reduces soil OC and consequently increases pH in agricultural systems. Similarly, Balesdent et al. (2000) showed that changes in soil microclimate, carbon content, and microbial activity under agricultural land use lead to an increase in soil pH.

pH reflects the acidity or alkalinity of the soil. Overall, soil analyses under different land uses indicated that the highest pH values occurred in fallow and wheat land uses, while the lowest pH was observed under alfalfa cultivation (Table 2). One possible explanation for the elevated pH in fallow and wheat soils is the presence of calcareous minerals, which increase calcium carbonate content. The higher pH under agricultural land use can also be attributed to the soil profile disturbance, which brings calcareous materials from subsurface horizons to the soil surface and reduces soil OC, ultimately leading to an increase in soil pH. Korkanc et al. (2008) reported that tillage operations reduce soil OC and consequently increase pH in agricultural lands. Similarly, Balesdent et al. (2000) demonstrated that changes in soil microclimate, carbon content, and microbial activity under agricultural land use contribute to increased soil pH.

The CCE contents under wheat, rangeland, alfalfa, and fallow land uses were 13%, 6.5%, 9.5%, and 13.5%, respectively, with the highest and lowest values observed in fallow and rangeland soils, respectively (Table 2). Land-use change can therefore have a significant influence on CCE content in the study area. The conversion of rangeland to agricultural land appears to increase carbonate accumulation, likely due to the reduced microbial activity and decreased soil OC content. The elevated CCE in the surface horizons of cultivated soils can be mainly attributed to the loss of the original surface horizon through erosion, exposure of underlying calcareous horizons, and the mixing of subsurface soil with surface soil during plowing. By enhancing aggregate stability and soil permeability, calcium carbonate reduces particle detachment and increases water infiltration, thereby decreasing the likelihood of soils for erosion. However, Zolfaghari and Hajabbasi (2008) studied the conversion of rangeland to agricultural land and reported that land use had no significant effect on CCE content. Calcium carbonate represents the dominant form of inorganic carbon in soils of arid and semi-arid regions, and its abundance reflects the presence of calcic horizons as well as soil nutrient status (Shakeri and Abtahi, 2020).

**Table 1.** Texture and texture components (sand, silt, and clay) in land uses studied

| Land use | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Soil texture |
|---|---|---|---|---|---|
| Wheat | 0-30 | 70 | 18 | 12 | Sandy loam |
| Alfalfa | 0-30 | 50 | 18 | 32 | Sandy clay loam |
| Rangeland | 0-30 | 58 | 16 | 26 | Sandy clay loam |
| Fallow | 0-30 | 48 | 20 | 32 | Sandy clay loam |

**Table 2.** Results of measuring chemical parameters in land uses studied

| Land use | pH | EC (ds/m) | OC (%) | N (%) | CCE (%) | P (ppm) | K (ppm) |
|---|---|---|---|---|---|---|---|
| Wheat | 7.95 | 2.2 | 0.64 | 0.055 | 13.2 | 5.0 | 162 |
| Alfalfa | 7.67 | 1.72 | 0.7 | 0.062 | 9.5 | 6.8 | 204 |
| Rangeland | 7.69 | 2.00 | 0.85 | 0.073 | 6.5 | 8.0 | 200 |
| Fallow | 7.95 | 1.76 | 0.96 | 0.082 | 13.5 | 8.8 | 222 |

EC: Electrical conductivity; OC: Organic carbon; CCE: Calcium carbonate equivalent.

The highest available potassium content was observed under fallow land use, whereas the lowest value occurred in wheat land use. This pattern suggests that leaching and the absence of potassium fertilizers under agricultural conditions contribute to the reduced available potassium in cultivated soils. Shakeri and Azadi (2022) similarly reported that one possible reason for decreased potassium concentrations in agricultural lands is the lack of potassium-containing fertilizer application combined with continuous potassium uptake by crops. Nabiollahy et al. (2006) also demonstrated that soil potassium levels vary with land use, a difference attributed to the higher clay and organic matter contents, as potassium is retained through electrostatic bonding on clay minerals and organic matter. Therefore, the relatively high potassium content observed under fallow land use is not unexpected, given its higher organic matter and clay contents compared to other land uses. Consistent with this, our results showed that fallow soils contained higher levels of OC and clay than soils under other land uses.

The amounts of available phosphorus measured under wheat, rangeland, alfalfa, and fallow land uses were 5, 8, 6.8, and 8.8 ppm, respectively, with the lowest value observed in wheat land use and the highest in fallow land use (Table 2). Since phosphorus is more strongly associated with fine soil particles than with coarse particles, a reduction in fine fractions results in greater phosphorus losses (Jalali and Peikam, 2013). Accordingly, the lower phosphorus content in wheat soils can be attributed to the reduced clay fraction observed under this land use. Although phosphorus is abundant in the Earth's crust, its availability to the plants is often limited, leading to excessive use of phosphorus fertilizers in agricultural systems. Soil depth, physicochemical properties, land use, and management practices strongly influence phosphorus distribution and availability, highlighting the need for a comprehensive understanding of phosphorus dynamics to optimize its agricultural use while minimizing environmental impacts (Niederberger et al., 2019; Rahman et al., 2021). Additionally, wheat cultivation results in substantial nutrient removal, as potassium is taken up both in the grain and in the straw and stubble, thereby increasing phosphorus removal compared with other land uses. Inadequate fertilization management can further contribute to the reduced soil phosphorus levels under wheat cultivation.

*Micromorphological studies in selected different land uses*

The soil color under wheat land use was reddish brown (Fig. 2a; Table 3). This red background color may be attributed to the presence of amorphous iron gels. It should be noted that soil color recognition is influenced by light reflection, thin-section thickness, and magnification. For instance, the clay background in a 30 μm thin section appears red but gradually turns yellow as thickness increases and becomes darker with further thickening. Similarly, nodules may appear dark at low magnification but show different visual characteristics at higher magnification. Soil color is an important indicator of soil composition; generally, darker soils contain higher amounts of OC than lighter soils. Iron compounds also play a significant role in determining soil color. Red soils are typically associated with hematite ($Fe_2O_3$), whereas yellowish-brown soils contain limonite ($Fe_2O_3 \cdot xH_2O$). Gray or bluish-gray colors indicate poor aeration, water stagnation, and the reduction of iron, where ferrous oxide (FeO) is the dominant iron form. The presence of yellow or red mottles or streaks within gray soils reflects alternating oxidation–reduction conditions.

Under wheat land use, agricultural practices significantly influenced soil physical properties such as porosity, water infiltration, and bulk density (Katswario et al., 2002). These changes were reflected in the presence of platy voids observed in this land use (Fig. 2c). The occurrence of cavities containing traces of organic components, accounting for less than 1%, indicates a decline in soil quality under cultivation (Shamsi Mahmoodabadi and Khormali, 2011). Additionally, the presence of large quantities of carbonates imparted a whitish or grayish appearance to the soil. The most prominent pedogenic features observed in the wheat land use were calcium carbonate crystals and iron and manganese compounds. The dominant microstructural forms included subangular blocky (cubic) and spongy substructures. Fig. 2b illustrates the relative distribution of coarse and fine components in an open porphyritic pattern, where fine and coarse materials are widely separated. In this pattern, nearly all pores were filled with soft material, and bridged pores were absent. Fig. 2c also shows opaque and dark minerals, which appear black under both PPL and XPL.

The experimental results indicated that the highest OC content occurred under fallow land use. The blackish-brown soil color observed in this land use reflects improved soil quality and surface cover. Fig. 3a shows a rock fragment with aerated minerals undergoing weathering, ultimately contributing to soil formation; a channel between the rock fragment and surrounding soil is also visible. Fig. 3b presents the same feature under PPL. Fig. 3c illustrates the soil microstructures under fallow land use, which were predominantly subangular blocky and granular in form. Soil grains were separated by compound packing voids and were generally non-accommodated, with few or no simple voids present. Compound packing voids were a dominant feature in this section and formed due to the poor compaction of soil components. These voids lacked accommodating surfaces, exhibited equal or elongated shapes, were mostly interconnected, and collectively formed the textural porosity of the soil. In such voids, spaces occur between non-accommodating aggregates. Fig. 3d presents another type of soil void observed under fallow land use, further highlighting the well-developed pore system associated with this land-use type.

The aggregate color under alfalfa land use was darker than that observed under wheat cultivation, indicating a higher OC content compared to wheat soils. As shown in Fig. 4a, one of the most prominent pedogenic features in the alfalfa soil was the presence of calcium carbonate crystals along with iron and manganese compounds. In many cases, lime nodules were observed to be impregnated with iron oxides. Another common calcareous feature was the presence of micritic calcite coatings in the form of overlying and underlying layers adjacent to the soil pores. Fig. 4a also illustrates the occurrence of iron oxides in alfalfa soils, where iron oxide can be seen progressively filling soil channels over time.

Alfalfa plays an important role in improving soil fertility and aeration. Its straight, thick, and deep root system creates channels in the soil that enhance aeration, as illustrated in Fig. 4b. Fig. 4c shows that the dominant pore types in alfalfa soils were compound packing voids, and the presence of opaque and dark minerals was also evident. However, the number of pores observed under alfalfa land use was lower than that under wheat cultivation. Stoops (2007) attributed reductions in pore size and irregular pore shapes to the influence of external physical factors, particularly the use of agricultural machinery and tillage practices. The structured pores observed in this land use reflect root growth, penetration, and biological activity, highlighting the role of living organisms in pore formation. Fig. 4d shows manganese oxides coating pore walls and forming circular features. In this section, a porostriated b-fabric was also observed, with clay domains in the micromass oriented parallel to pore surfaces. B-fabric describes the origin, orientation, and distribution patterns of interference colors within the micromass.

In rangeland soils, Fig. 5a shows that mineral particles were generally finer. Similar to other land uses, pedogenic features included calcium carbonate crystals in the form of lithogenic nodules. These nodules were commonly observed within the soil matrix, particularly along pore walls, and some were present within the pores themselves, which were predominantly compound packing voids (Fig. 5b). In addition, large channels were observed in rangeland soils, occupying approximately 20–30% of the thin-section area. This indicates that a wide variety of voids developed in the surface layer under natural rangeland conditions as a result of diverse microstructural arrangements. The dominant void types in rangeland soils were packing and channel voids. In both rangeland and fallow land uses, higher OC contents, greater soil fauna activity, and the absence of tillage resulted in larger voids and higher overall porosity compared to wheat and alfalfa land uses.

Thus, the micromorphological analysis of microstructure and micropores revealed that conversion of rangeland and fallow soils to agricultural land uses (wheat and alfalfa) led to a transition from crumb and granular microstructures with compound packing voids to blocky microstructures characterized by planar voids. No clear differences were observed in b-fabric or calcitic pedofeatures between agricultural and non-agricultural land uses.

In most horizons under both agricultural and pasture land uses, pore surfaces were often irregular, and lime was frequently observed within pores and along their margins. A comparison between cultivated and pasture lands indicated that the overall percentage of pores increased under cultivated land use. In pasture land use, the proportion of pores in the surface horizons of the studied profiles ranged from 19% to 24%, which can be attributed to the higher porosity and the presence of finer soil particles. In many horizons of the cultivated soils, incomplete pedality was observed in thin sections. Nevertheless, signs of reduced grain integrity and finer soil texture were evident in several horizons, which appears to result from repeated machinery traffic and plowing operations.

Soil structure was predominantly of a complex type, consisting of a mixture of spheroidal and granular forms. The dominant pore types were channels and vughs (cosmetic holes), while the number of planar pores increased noticeably. This observation is consistent with the findings of Khormali and Ajami (2011), who reported that, with progressive conversion from pasture to agricultural land use, channel pores decrease in both size and abundance, while planar pores increase. Ayoubi et al. (2014) also noted that channel pores are more prevalent in pasture and forest land uses due to the greater faunal activity and lower soil compaction, which enhances soil aeration.

In contrast, agricultural land use is strongly influenced by farming operations, which significantly affect soil physical properties such as porosity, water infiltration, and bulk density. The higher organic matter content and well-developed soil aggregates in pasture and fallow land uses promote the formation of larger pores compared to agricultural soils. These larger pores play a beneficial role in facilitating root penetration and improving water movement within the soil profile.

## CONCLUSION

The results of the physical and chemical analyses, together with micromorphological investigations across different land uses, showed that soil texture remained unchanged as sandy clay loam under most land uses, while an increase in sand content under wheat cultivation led to a change in texture to sandy loam. Soil OC, total nitrogen, and phosphorus contents were highest under rangeland and fallow land uses and lowest under wheat cultivation. In contrast, CCE exhibited the highest values under fallow and wheat land uses, with the lowest CCE observed in rangeland soils. pH reached its highest level under fallow land use and its lowest level under rangeland use. Micromorphological observations indicated that the dominant microstructures across the studied land uses were cubic, subangular blocky, and spongy, while the prevailing porosity patterns consisted mainly of packing and channel voids, with platy voids observed in some cases. Lime accumulations in the form of typic nodules, infillings, and calcareous coatings, as well as accumulations of iron and manganese oxides in the form of nodules and coatings, were observed across different land uses. The most prominent pedogenic features identified in thin sections were calcium carbonate crystals and iron and manganese compounds. Micromorphological results further demonstrated that vegetation was the primary factor influencing soil microstructure and void characteristics, and thus the physical properties of the soil. Other soil properties were only slightly affected by changes in land use over the time scale considered, although these effects are expected to become more pronounced with continued soil development and maturation. Overall, this study underscores the importance of adopting conservation-oriented management practices to prevent soil degradation associated with non-normative land-use practices.

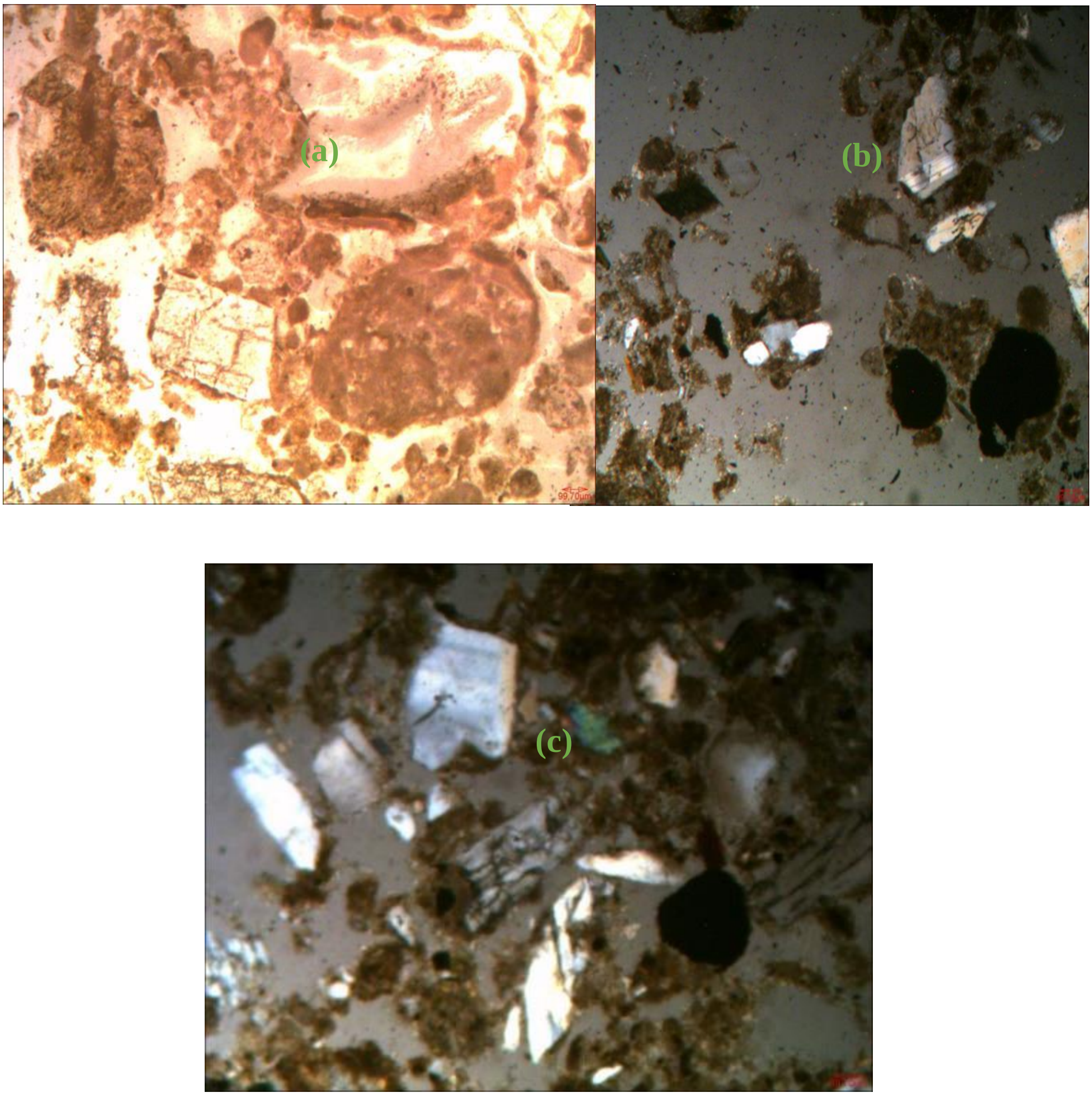


**Fig. 2.** Thin section of wheat cultivation soils in (a) plane polarized light and (b, c) crossed polarized light.

**Table 3.** Soil micromorphological properties

| Property | Wheat land use | Fallow land use | Alfalfa land use | Rangeland land use |
|---|---|---|---|---|
| Soil Color | Reddish brown due to Fe gels; color affected by section thickness, magnification and reflection. Dark soils = more OC; Red = hematite, Yellow = limonite, Gray/blue = reduced Fe | Blackish brown (high OC); represents good soil quality | Darker aggregates (higher OC); white/gray with carbonates; Fe/Mn oxides visible | Color varies; lithogenic nodules and Fe/Mn compounds present |
| Voids / Porosity | Platy cavities with < 1% organic traces; decreased quality seen via pores | Compound packing voids; poor compaction, elongated, interconnected; more and larger voids | Greater root channels; fewer pores than wheat, with observed compound packing voids | Packing and channel voids; large channels fill up to 20-30% of sections; large holes from more OM & fauna activity |
| Pedogenic Features | Crystals of $CaCO_3$, Fe/Mn compounds; subangular cubic and spongy substructure | Presence of $CaCO_3$ crystals; subangular blocky & granular microstructures | $CaCO_3$ crystals, iron/manganese, calcite coatings near pores | Nodules visible in soil matrix and pores ($CaCO_3$) |
| Mineral Components | Opaque and dark minerals visible | Aerated rock fragments lead to soil formation; minerals separated by packing voids | Opaque & dark minerals; Fe oxide in root channels, Mn oxide on pores | Minerals become finer; pedogenic $CaCO_3$ crystals present |
| Soil Structure | Open porphyritic type; fine & coarse components separated; most pores filled with soft material | Subangular blocky and granular microstructures; separated by compound packing voids | Straight/thick roots creating channels; compound packing voids | Mixture of spherical and granular; planar voids in agricultural soils |
| Effects of Land Use | Farming decreases porosity, increases bulk density | Fallow improves OM & porosity; less tillage increases size and number of voids | Alfalfa increases fertility, aeration via deep roots | Rangeland has less soil compaction, large pores for root and water movement |

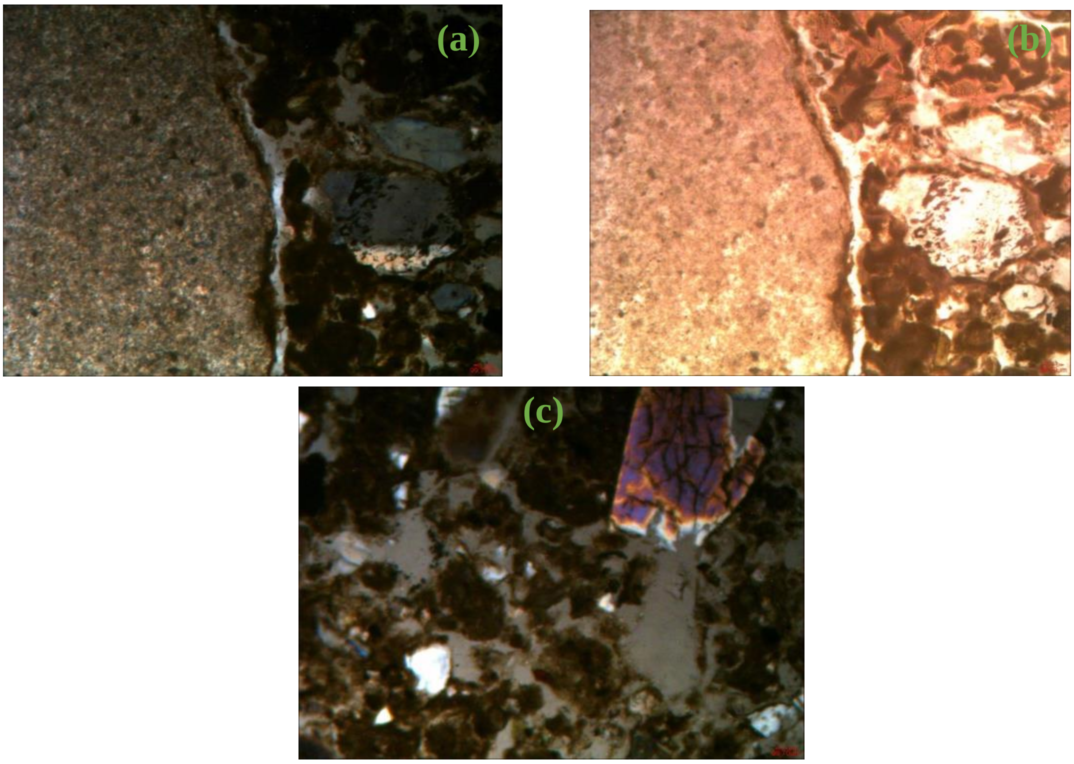


**Fig. 3.** Thin section of fallow land soils in (a, c) crossed polarized light and (b) plane polarized light.

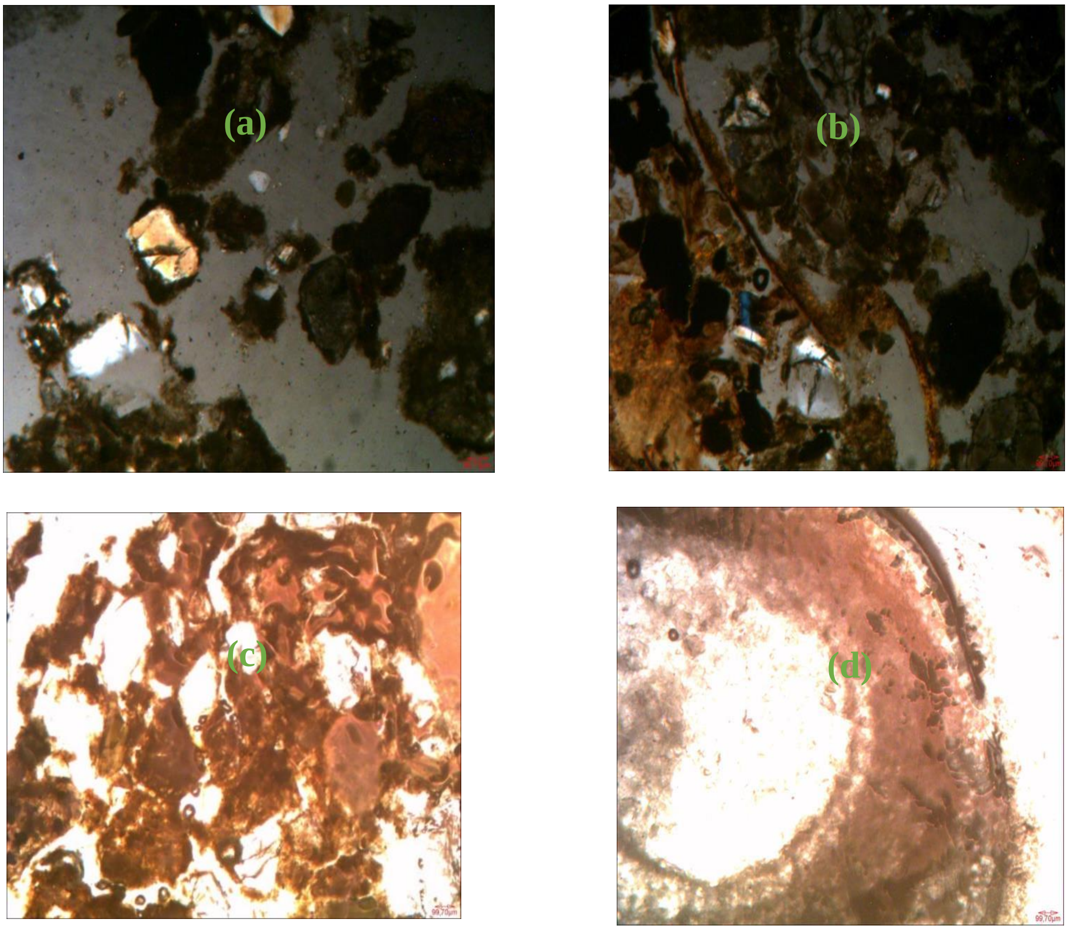


**Fig. 4.** Thin section of alfalfa cultivation soils in (a, b) crossed polarized light and (c, d) plane polarized light.

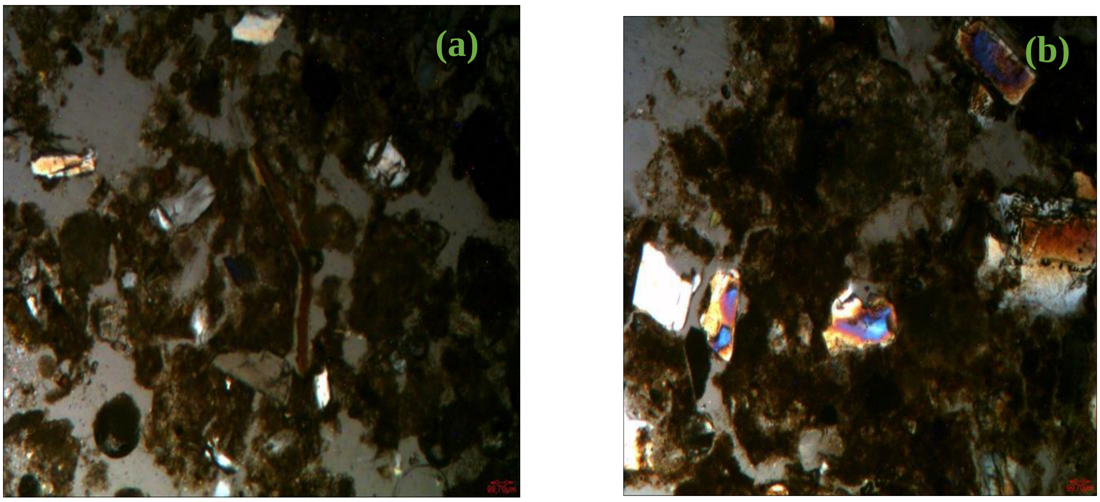


**Fig. 5.** Thin section of rangeland soils in (a) plane polarized light and (b) crossed polarized light.

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Conceptualization: Ashraf Malekian and Sirous Shakeri; Methodology: Sirous Shakeri; Software: Abolfazl Azadi; Validation: Sirous Shakeri and Abolfazl Azadi; Formal analysis: Ashraf Malekian; Investigation: Sirous Shakeri; Resources: Ashraf Malekian and Abolfazl Azadi; Data curation: Sirous Shakeri; Writing—original draft preparation: Sirous Shakeri and Abolfazl Azadi; Writing—review and editing: Ashraf Malekian; Visualization: Abolfazl Azadi and Sirous Shakeri; Supervision: Abolfazl Azadi; Project administration: Sirous Shakeri.

**DECLARATION OF COMPETING INTEREST**

The authors declare no conflicts of interest.

**ETHICAL STATEMENT**

Not applicable

**DATA AVAIIBILITY**

All data are available upon reasonable request.

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