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Study on the impact of biological crusts on soil micromorphological properties in the Incheh Borun region, Iran

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ABSTRACT

Biological soil crusts play a vital role in soil characteristics. Therefore, the objective of this study was to investigate the influences of biological soil crusts on micro-morphological characteristics of soils in the Incheh Borun region of Golestan in Northern province, Iran. The soil of this area is classified as *Calcisol*. The study area included by three plots (25m x 25m bio-shells), as well as a plot (25m x 25m) for indentyfing physical crusts and also intact samples were taken from each plot using the Kubina boxes. Then, the micromorphological characteristics of soil under their surface (with depths 0-2cm) were analyzed. The microstructure of the soil under the cyanobacteria, lichen and moss was better than the physical crust. This was due to the low content of organic matter and low biological activity in the physical crust. Also, soil porosity under the moss and lichen crusts were channel and in cyanobacteria and physical crusts were chamber. There were animal and root residues and also Mollusca shells in the soil under the biological soil crusts, which indicates the presence of biological activity in these shells. Nodules of calcium carbonate in biocrusts were more than the physical crusts which indicates good structure and porosity of soils under the biological soil crusts in contrast to physical ones to increase the soil penetration and formation of these features over the time. Therefore, the presence of biocrusts (moss crusts) with increasing soil porosity and providing suitable environmental for biological activity according to the pedo-feature of animal residues and plant roots inside their holes can help to improve soil characteristics.

Keywords: Biocrusts, porosity, microstructure, b-fabric, pedo-feature.

1. Introduction

Biological soil crusts consist of different types of cyanobacteria, eukaryotic algae, lichens, mosses, decomposing organisms including bacteria, fungi, and the food web of animals (Belnap et al., 2003). These organisms dwelling on the soil surface are of great importance as they cover about 12% of Earth (Rodríguez-Caballero et al., 2018). Biological crusts improve the physical properties of soils. The microorganisms residing in them are in direct contact with the soil. They accumulate on the soil surface and increase the soil stability (Belnap et al., 2003). Many studies have been done on the effect of biological soil crusts on ecosystem function one of which is its effect on increasing soil resistance to erosion. In recent studies, biocrusts have been recognized as vital and versatile ecosystem. Some of their roles include: 1. Creating or changing soil nutrient reserves through stabilization, trapping dust (Elbert et al., 2012) and their effect on the nutrient cycle (Strauss et al., 2012), 2. Effect on soil hydrological characteristics such as water balance (Chamizo et al., 2016) and 3. Thermal energy balance of the ecosystem (Coradeau et al., 2016; Rutherford et al., 2017).

Physical soil crusts are formed in different climatic conditions, but they are more widespread in the soils of arid and semi-arid regions, both in natural and cultivated systems (Gerasimova and Lebedeva, 2018). In different areas, surface crusts usually form on soils with low organic carbon content (Poesen and Neaeing, 1993). In recent years, soil degradation due to overuse of the earth's capacity has caused the formation of surface physical crusts in all types of soils (Pagliai, 2004). The physical crust has a very negative effect on plant germination and the speed of water penetration into the soil and the root zone of plants (Pagliai, 2008). Also, the reduction of water infiltration causes irrigation problems, runoff and soil losses due to erosion increased (Moore and Singer, 1990). Numerous studies show that the use of no-tillage systems reduces the formation of physical crusts by improving soil structure. In such studies, soil micromorphology has increased our understanding of crust characteristics and area management.

Investigating soil samples using microscopic and ultramicroscopic techniques is called micromorphology. It aims to identify different soil components and determine the temporal relationships. In fact, micromorphology is the science of studying the micro-fabric of soil in its natural and intact state using thin sections and microscopic methods. Although micromorphology is mainly used for the explanation of pedogenic phenomena, this science has a wide application in other branches of soil science such as physics, chemistry and soil biology (Wilson, 2020). The purpose of micromorphology is to understand the formation and deformation of soil natural features such as clay crusts and nodules or artificial ones such as crusts resulting from irrigation as well as hard pans created due to plowing. Therefore, micromorphology is considered a key tool to investigate soil genesis, classification, and soil management (Stoops, 2003). In soil micromorphology, soil constituents and the spatial relationships of these components with each other are studied. It also involves the investigation of the occurring phenomena with the naked eye. The importance of micromorphology in comparison with other soil study techniques is macromorphological and physicochemical investigations. The investigation of soil components in terms of size, shape and arrangement is emphasized, in micromorphological methods (Hamard et al., 2019). In addition, micromorphology is an important part of soil-plant interaction studies. Also, soil-forming factors are usually specific and dominant in each type of soil and thus it is a reflection of the balance between them. Some of these factors may not so be recognizable by macromorphological observations. However, micromorphology is a method to describe the effects of all soil-forming factors, both those visible with the naked eye and those that are not, and is used to confirm and complement field studies. The existence of different crusts on the surface of desert lands is due to the changes in porosity and the size distribution of the pores which can be effective in the formation of soil grains and changes the soil structure. Two-dimensional images of pores provide information about the number, surface, perimeter, diameter, shape, arrangement and size distribution of pores, which can be used to evaluate the changes in soil structure on a micrometric scale (Asem Hassan, 2022). In fact, this technique allows the quantitative evaluation of soil characteristics that are usually clearly visible in the field. According to Asem Hassan (2022), the geometric space of soil pores is effective in root growth and the movement of water and air in the soil, which affect the drainage and permeability of water in the soil. Yazdani et al. (2008) studied the micromorphological characteristics of soils with biological crust in Jahrom region and reported that the types of spongy to very fine granular microstructures were developed with strong separation, cubic without fine angles and in some parts mass microstructure was seen. Most of the pores were channels, cells, and vugh. The presence of spherical and oval cavities with a width of 1 to 400 micrometers under the crust with smooth walls was due to the reaction between biological crusts and soil. The main types of organic compounds including fresh fungal hyphae and the remains of disintegrated lichens were observed in the sections.

Defarge et al. (2009) reported that soil samples with dense biological crust were very porous and had a high water holding capacity. They also observed that the soil thin sections with a dense crust that had been subjected to microscopic examination had 50-60 micrometer pores.

Malam Issa et al. (2009) reported that polysaccharides and hydrophobic polymers secreted from biological soil crusts had remarkable effect on soil porosity. They observed that soils with dense biological crusts were more porous compared to the others.

Kesalkheh et al. (2012) examined density and shape of biological crusts as soil surface cover and these biological crusts protected, improved the porosity of soil structure.

Loess Plateau is one of the most sensitive areas to erosion in the world, and biological soil crusts increase the connection between soil particles and prevent the erosion of such soils. The objective of this study was investigation the effect of micromorphological characteristics on loess soils under the biological crusts in the Incheh Borun region of Iran, compared to physical crusts.

2. Methods

a) Description of the study area

Incheh Borun with a latitude of 37° 28” N and a longitude of 54°42” E and situated at -10 m above sea level was chosen as the study area that is a city in, and the capital of Golestan province, Iran. In this region, we found the most distribution of different sequences of biological crusts, which include: physical crust, cyanobacteria, lichen and moss (shown as a Fig. S1 in supplementary material). Also, this area has loess deposits, the sequence of biological crusts is placed on these hazardous soils and stabilizes them and prevents them from being transported by water and wind (water and wind erosion). The soil of this area is classified as *Calcisol* (World Reference Base for Soil Resources (WRB), 2022).

b) Soil sampling

After the field study in the Incheh Borun region and identification of the different sequences of biological crusts in this area, three 25m x 25m plots were prepared in the place with the highest frequency of biological crusts (Fig. 1).

In order to determine the effects of biocrusts on the micromorphological characteristics of the soil, intact samples were taken from each plot using the Kubina box from the surface layers of soil under the different biocrusts (cyanobacteria, lichen and moss) and sent to the laboratory.

Also, biological crust-free soil (physical crust) in this region served as a control to the soil with biological crusts and was sampled in the same manner as mentioned above.

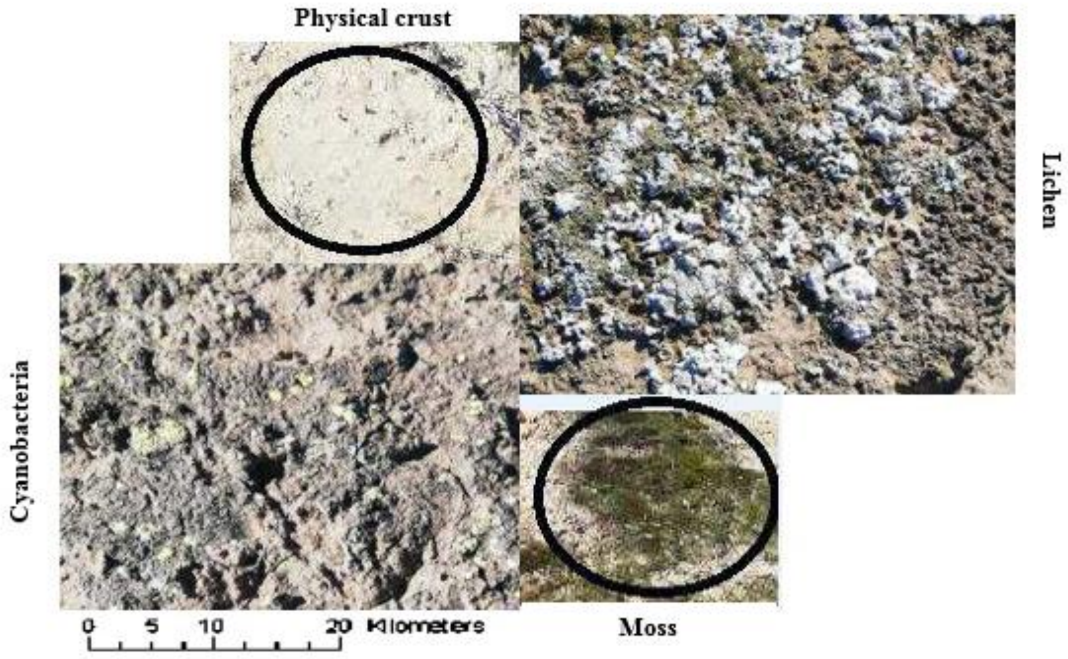

Figure 1. The different sequences of physico-biological shells.

Table 1. Micromorphological description of the soil under the biological and physical crusts

Crusts	Porosity	Microstructure	b-fabric	Pedo-feature	Minerals
Physical crust	Chamber	Sub-angular blocky	Crystalline	-	Quartz
Cyanobacteria	Chamber	Crumb	Crystalline	Nodules of calcium carbonate, Animal remain, root, Mollusc shell	Quartz-calcite
Lichen	Channel	Granular	Crystalline	Nodules of calcium carbonate, Animal remain, root, Mollusc shell	Quartz-calcite
Moss	Channel	Cubic	Crystalline	Nodules of calcium carbonate, Animal remain, root, Mollusc shell	Quartz-calcite

c) Laboratory studies

The intact samples were placed in the open space to dry. Then, 60% polyester resin, 40% acetone as diluent, 14 drops of methyl ethyl ketone catalyst and 7 drops of cobalt as hardener were used to saturate the samples. Impregnation of the samples was done in vacuum and in several stages with the gradual addition of resin and the hardening time of the samples lasted about 4 weeks. Cutting and preparation of thin sections was done and the thickness considered in this study was 30 microns (Bullock et al., 1985). Samples studied by polarized microscope in two lights (PPL: plane polarized light and XPL: Crossed polarized light) with a magnification of 2.5 and the definitions provided by method of Stoops (2010).

d) Statistical Analysis

The obtained data were collected and categorized in Excel (2016) software.

3. Result and discussion

In order to identify soil formation processes and study parameters influenced by management, micromorphological techniques are used. Some of these parameters are: the content and distribution of soil organic matter, soil porosity, soil structure, etc. Also, considering the importance of microscopic studies in investigating the changes and developments as closely as possible, in this section, we examined and evaluated some important micromorphological parameters, including microstructure, porosity, b-fabric, pedo-feature and mineral types (Table 1).

A) Porosity

According to Figure 2, the porosity of soil under the moss and lichen crusts was channel, whereas those under the cyanobacteria and physical crusts were chamber.

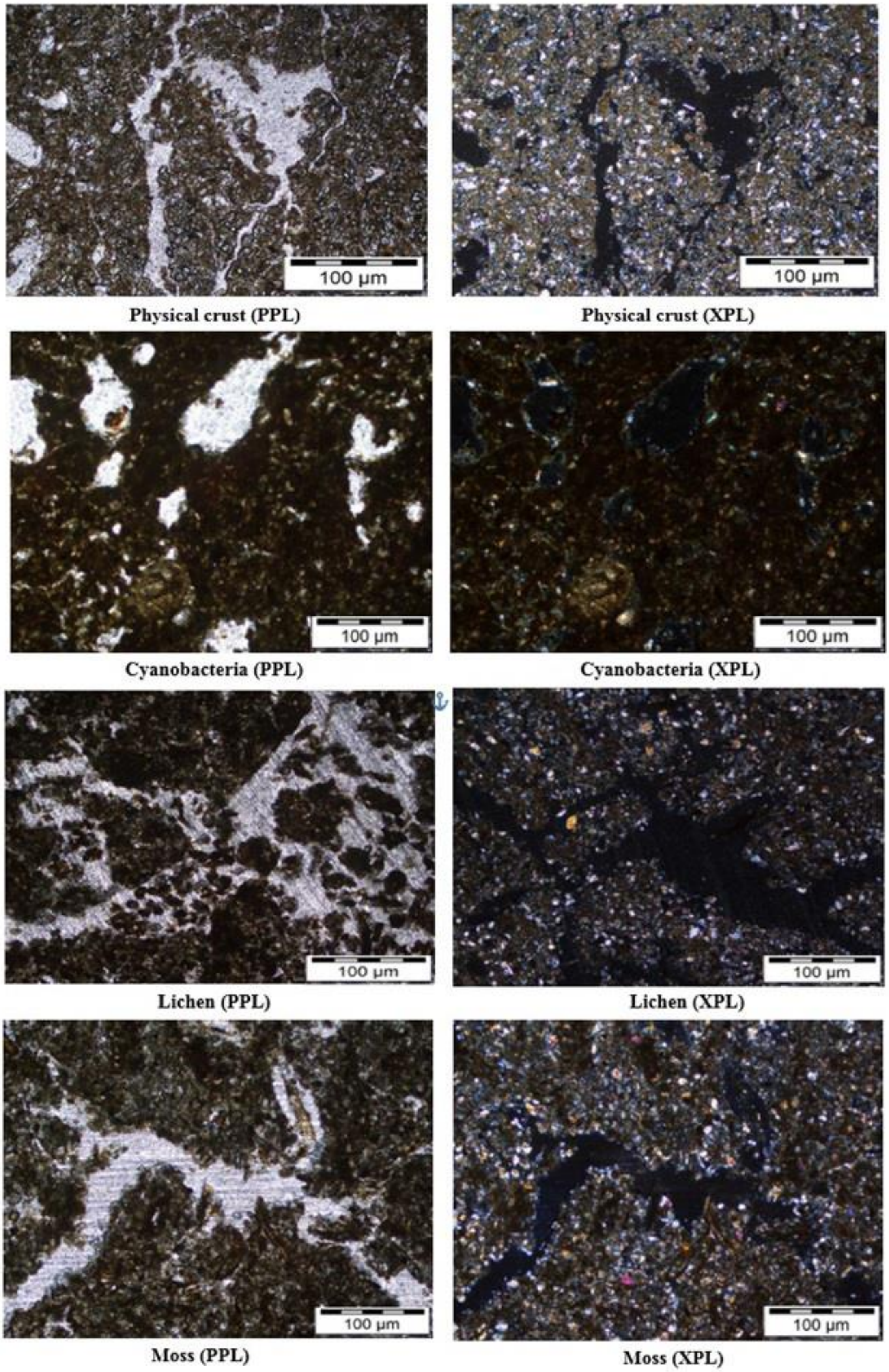

Fig. 2. chamber porosity in physical and cyanobacteria crusts, channel porosity of lichen and Moss

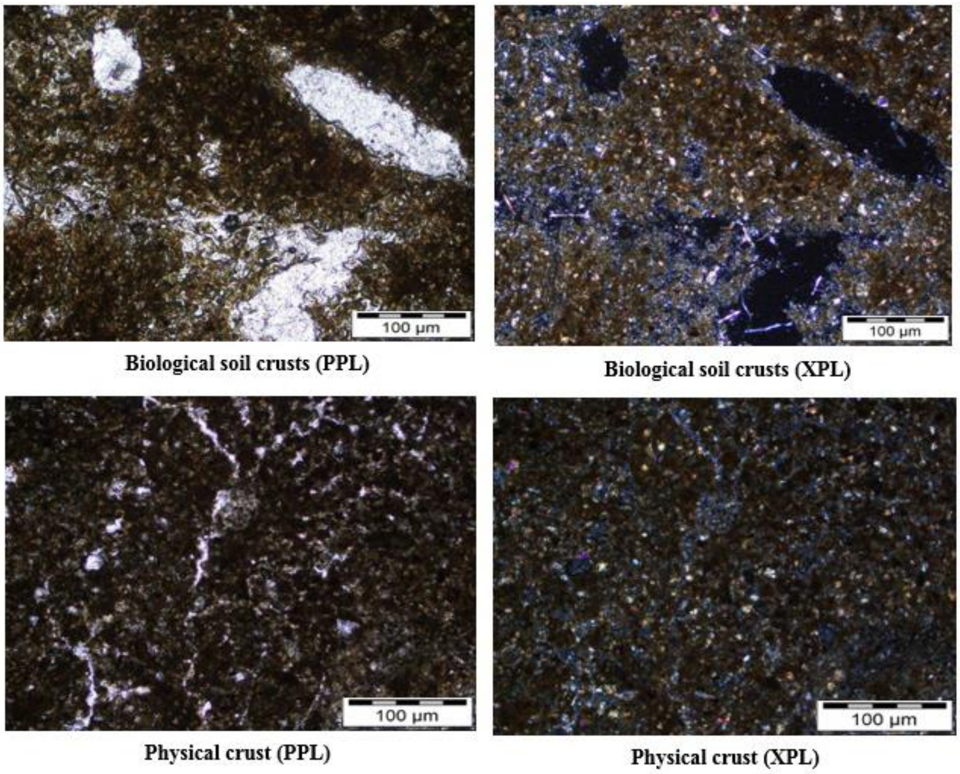

Fig. 3. crystalline calcite b-fabric in soil under biological and physical crusts

Generally, the porosity of the soil under the moss and lichen crusts are channel and plate types, which indicates the improvement of the soil structure and the existence of biological activity.

Also, the presence of channel indicates the penetration and increase of root growth in soil, as well as an increase in the biological activity of organisms (Kemp et al., 2004). On the other hand, the presence of chamber porosity in the soil under the cyanobacteria and physical crusts indicates the lack of a good structure and biological activity. This is due to the presence of these two crusts in lower sequences. However, from the initial sequence (physical crust) to the final sequence (moss crust) in the study area, we observed the improvement of the soil structure and the increase of biological activity. These events are very important especially in the desert conditions of this region. Also, the higher organic matter in the soil under the moss and lichen crusts is higher compared with the soil under the cyanobacteria and physical crusts. Therefore, soil particles are bound tightly to each other, which improves the soil structure. Nimmo (2013) reported that biological soil crusts, changed the placement of soil mineral particles due to their high ability in granulation compared to physical crusts. This will result in an increased soil porosity.

b) Microstructure

The study of thin sections of soils showed the microstructure of the soil under the moss crust was cubic and lichen crust was granular. Also, the microstructure of soil under the cyanobacteria and the physical crust were sub-angular blocky and crumb and had a weak structure. This is due to the low organic matter and biological activity in these two crusts. In contrast the moss and lichen crusts had a more stable structure due to containing higher organic matter. Also, the soil structure depends on the size distribution of particles, organic matter, transport processes and microorganisms. The presence of biological crusts results in the secretion of extracellular polysaccharides, and as a result, soil particles bind to each other and soil granulation increases (Belnap, 2006). The studies of Asta et al. (2001) showed that lichen roots stabilize soil structure by creating bonds between soil mineral particles. The sticky structures of moss and lichen increase the soil's resistance to water and wind erosion. Increased frequency number of cyanobacteria filaments and the adhesive structures of lichen and moss on the other hand, improves the ability of these organisms to stabilize soils. Therefore, trapping of the soil particles by fungal hyphae of the lichen should be considered as an important mechanisms of soil protection by biological crusts (Asta et al., 2001).

c) fabric

The b-fabric of the study samples were calcific crystallite (Fig. 3). According to the study of Khormali et al.

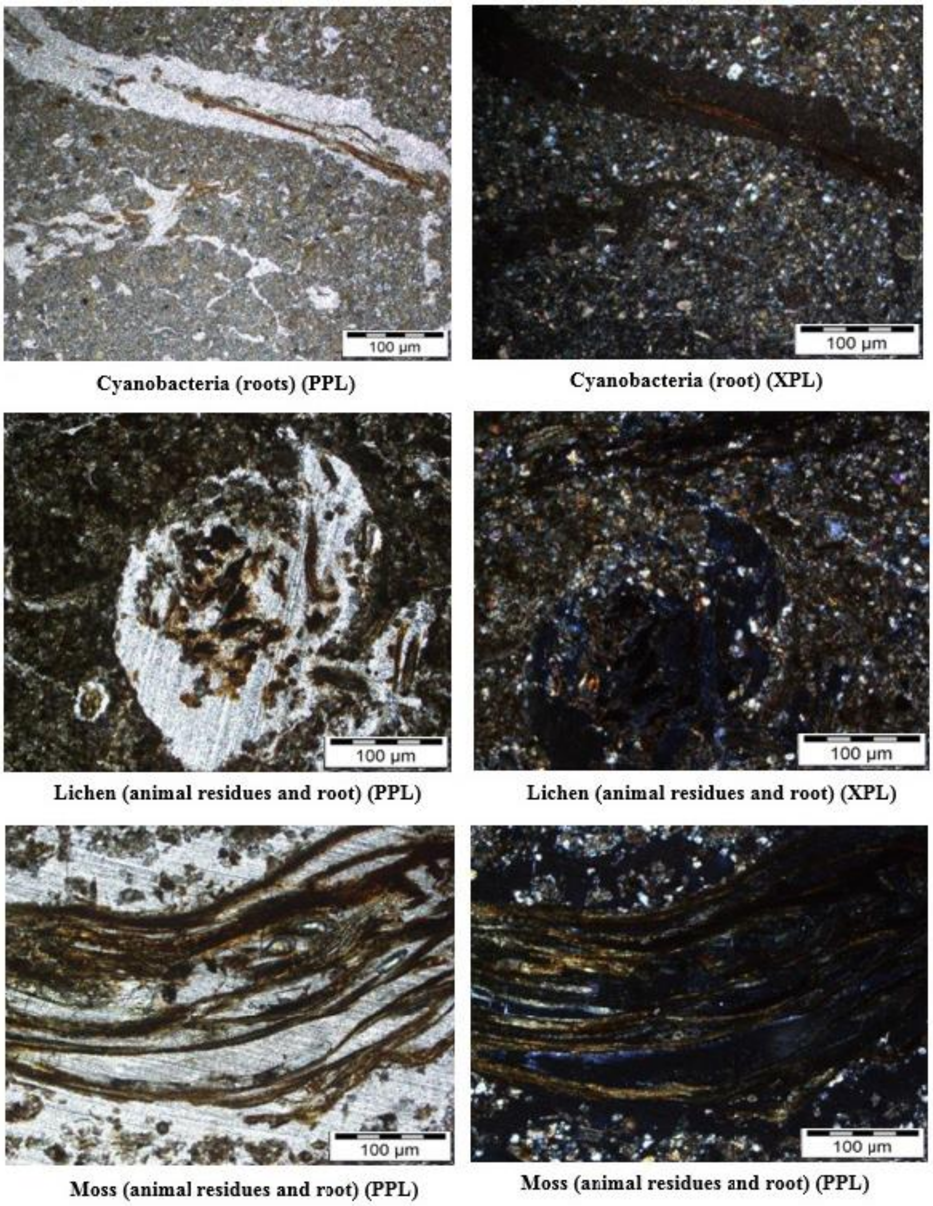

Fig. 4. Pedo-feature caused by animal and root residues in biological soil crusts

(2003), b-fabric indicates soil development. The crystalline b-fabric of soil is resulted from the presence of a large amounts of calcareous compounds that have been accumulated by lichen as a thin layer. This layer can provide a suitable protective tool to prevent the soil erosion in the study area and improve soil stability. Khormali et al. (2003) reported that the existence of crystalline b-fabric is due to the presence of large amounts of carbonates especially lime in the soil. The crystalline b-fabric was resulted from the abundance of fine calcite particles (Kemp et al., 2003).

d) Pedo-feature

- Animal and root residues

One of the signs of biological activity in the soil under the surface of biological crusts is the presence of spherical microstructures, pedo-feature of animal residues and plant roots inside the holes (Kemp et al., 2003). The abundance of pedo-feature caused by animal residues in biocrusts indicates suitable environmental conditions for biological activity, and its scarcity in physical crusts reveals the limitation of this function. The results showed that the highest abundance of animal residues and root were moss> lichen> cyanobacteria in order. This indicates the biological activity of soil organisms in these three crusts compared to the physical crust (Fig. 4).

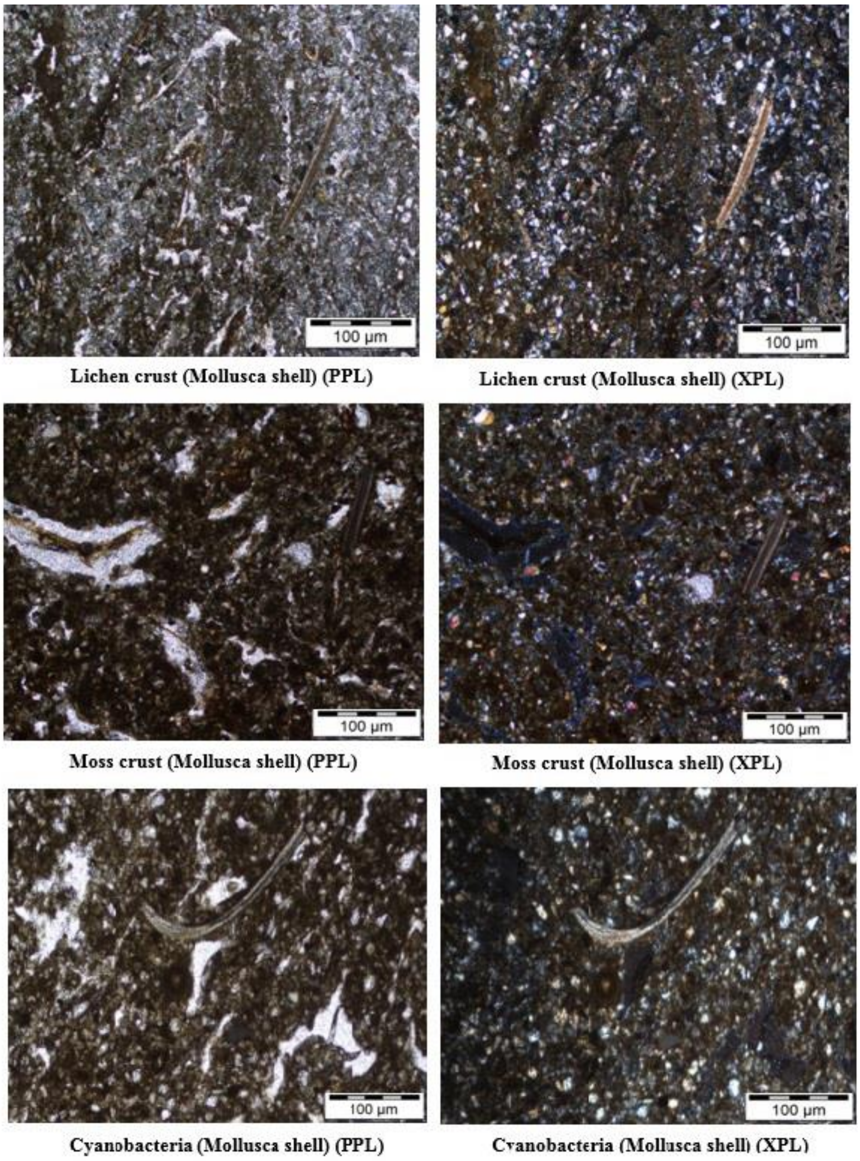

Fig. 5. Pedofeature caused by Mollusca shell in biological soil crusts

- Mollusca shells

A Mollusca or Mollusk shell is usually a calcareous exoskeleton that supports, and protects the soft parts of an animal in the phylum mollusk, which includes snails, clams, mollusk, and several other classes (Marin and Luquet, 2004). Mollusca fossils were found in the soil below the surface of the cyanobacteria, lichen and moss biological crust, which, in addition to confirming the biological activity of these biocrusts, indicates that this study area was under water in the past climatic conditions (Fig. 5). The results of our study are consistent with Canti (2017).

- Calcium Carbonate

The formation of pedogenic calcium carbonate is primarily influenced by parent material, climate, and vegetation (Wright, 1990). The formation of pedogenic carbonate is the result of a complex process including dissolution (weathering), transport and precipitation (Khormali et al., 2006). Depending on physical, chemical, and biological activities in the soil, the accumulation of calcium carbonate can create various forms in the soil (Kemp et al., 2003). Calcium carbonate is one of the secondary characteristics of loess. In the present micromorphological study, a wide range of calcium carbonate forms were found. Also, Khormali et al. (2006) reported that depending on the physicochemical process and biological activity in the soil, the accumulation of calcium carbonate can produce different forms.

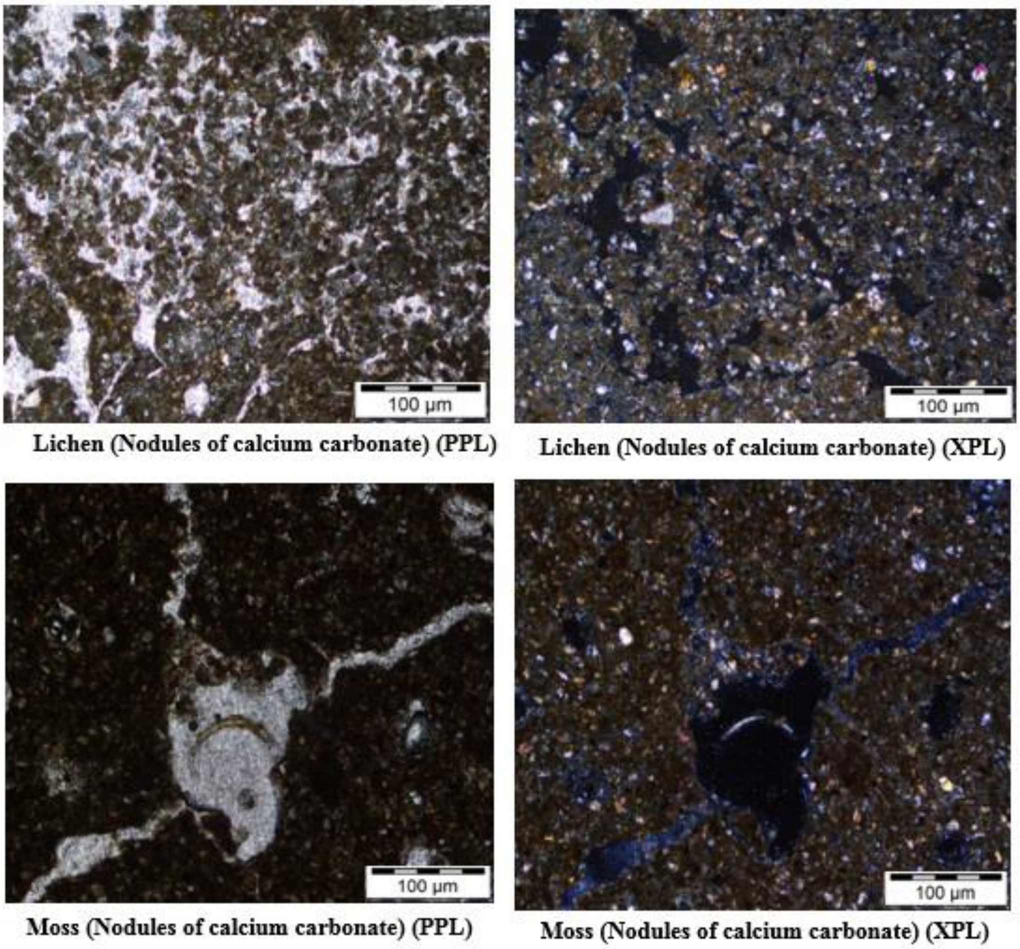

Fig. 6. Nodules of calcium carbonate in biological soil crusts

Nodules of calcium carbonate are the most dominant type of pedogenic carbonates. The formation and morphology of these nodules are determined by many factors, including dissolution and crystallization processes, salt concentration, soil texture (Wieder and Yaalon, 1982), soil stability (Segal and Stoops, 1972) and suitable conditions for calcium carbonate precipitation. The results of micromorphology showed that the amount of calcium carbonate nodules in biocrusts was more than physical crust (Fig. 6). In the soil under the surface of biological crusts, due to the high permeability of water, calcium carbonate compounds were accumulated in various forms, including nodules. However, in the subsoil of physical crusts, due to the low permeability of water, the accumulation of calcium carbonate decreased. Therefore, the calcium carbonate compounds, formation and development of this pedogenetic effects in the soil are hindered.

4. Conclusion

According to the obtained results, it was observed that the presence of biological crusts on the surface of loess soils significantly increases soil stabilization and prevents their erosion. Moss crust was located at the end of the sequence and thus, had a greater effect on soil properties. Therefore, moss crusts with increasing soil porosity and providing suitable environmental for biological activity according to the pedo-feature of animal residues and plant roots inside their holes can help to improve soil characteristics.

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