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Effects of biological soil crusts on some physicochemical characteristics of rangeland soils of Alagol, Turkmen Sahra, NE Iran

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ABSTRACT

Salinity, water scarcity in the summer season, and grazing pressure are major problems in semi-arid ecosystems in the south-east region of the Caspian Sea where the Alagol rangelands of Turkmen Sahra (Golestan province) of North East Iran suffer from over-grazing and soil loss. This study investigated the influence of biological soil crusts (biocrusts) on soil physicochemical properties. Biocrusts create complex communities of specialized organisms composed of cyanobacteria, algae, microfungi, lichens, mosses and other microorganisms. Results have shown that bioencrusted soils increased levels of organic carbon, nitrogen, phosphorus, copper, and iron, and reduced pH, calcium carbonate, sodium, calcium, magnesium, sodium adsorption ratio and exchangeable sodium percentages compared to soils without biocrusts. Other positive influences of biocrusts on soil properties included increased infiltration (0.16 *v.* 0.081 cm min^{-1} for steady state rates), available water content, mean weight diameter of soil aggregates, geometric mean diameter and water stable aggregates. Bulk density was reduced under bioencrusted soils relative to non-biocrusts soils. In general, biocrusts had a positive effect on many soil properties and thus enhanced soil quality.

1. Introduction

Soil crusts are a major structural feature of surface soils and sediments, especially in arid and semi-arid regions (Fang et al., 2007). Soil crusts are divided into several types, including physical, chemical and biological soil crusts (Belnap et al., 2003a). Physical and biological soil crusts are the principal types of soil crusts (Miralles-Mellado et al., 2011), and are distributed in arid, semi-arid and sub-humid regions that constitute over 40% of the Earth's terrestrial surface (Belnap, 2006; Fang et al., 2007). Biological soil crusts (biocrusts) result from an intimate association between soil particles and cyanobacteria, algae, fungi, lichens and mosses which live on the surface or in the uppermost few millimeters of soils (Belnap et al., 2003a). These organisms and the extracellular polysaccharide materials associated with them connect soil particles together, creating a sticky living crust that covers the surface of many dry land regions in the worldwide (Belnap, 2006). Biocrusts occur on all major soil types and in almost all vegetative communities where sunlight can reach the soil surface (Belnap, 2006); they have low moisture requirements and a high tolerance of extreme temperatures and high ultraviolet (UV) light flux, thus enabling them to survive under conditions that can limit vascular plant growth (Belnap et al., 2003a). The species composition and external morphology of biocrusts vary according to the climatic regime and their successional status (Belnap, 2006). Pioneer or early successional biocrusts are composed mainly of bacteria, fungi and cyanobacteria (Büdel, 2005). In suitable climate conditions, after soil surfaces are stabilized by cyanobacteria, the lichens and bryophytes begin their colonization (Belnap, 2006), to form well-developed biocrusts, with the proportion of bacteria and cyanobacteria, algae, microfungi, lichens and bryophytes occurring in different combinations and abundances, depending on soils and climate (Büdel, 2005).

Although biocrusts contribute a minor proportion of the soil profile (less than one to a few millimeters in thickness), they play multiple roles, especially where water is scarce (Miralles-Mellado et al., 2011). At a fine scale, biocrusts can be considered as an ecological boundary because they control the flux of energy and materials in the interface between the atmosphere and the soil surface, as well as a soil and plant roots interface (Belnap et al., 2003b). Some of the functions that biocrusts influence include soil surface micro-topography (Rodríguez-Caballero et al., 2012), porosity (Miralles et al., 2012), infiltration (Eldridge et al., 2000; Xiao et al., 2011; Chamizo et al., 2012a; Rossi et al., 2012), water absorption and retention (Chamizo et al., 2012a),

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soil aggregation and stability (Chamizo et al., 2012b), sediment production (Chamizo et al., 2012a), evaporation, water and wind erosion (Belnap and Gillette, 1997), and nutrient retention (Reynolds et al., 2001). The presence of biocrusts have also been shown to increase fertility in plant interspaces in many ecosystems (Chamizo et al., 2012b), and can also alter local hydrology, leading that enhances water and nutrient availability, thereby promoting the establishment and development of vascular plant (Zhang et al., 2016).

Despite the documented importance of biocrusts globally (Belnap, 2006; Chamizo et al., 2012b; Bowker et al., 2013; Chen and Duan, 2015), few studies have been devoted to the influence of biocrusts on Iranian rangeland soils (e.g. Jafari et al., 2004). Turkmen Sahra, an important rangeland of Iran, is located in the Atrek area close to Alagol lake. This rangeland is severely degraded due to heavy grazing pressure and other human activities (Mirabzadeh-Ardakani, 2014). The aim of this study was to: 1) determine the effects of biocrusts on soil hydrology, 2) measure how biocrusts affect soil chemical and physical properties, and 3) document the vertical variation in soil physicochemical properties (at depths of 0–5 and 5–15 cm) for soils with and without biocrusts. To this end, the hypotheses that (a) biocrusts would affect soil hydrology with increasing infiltration rate, and (b) positively modify local hydrology, soil stability, nutrient retention, etc. by their presence, and that (c) soil physical and chemical properties would be different in soils covered with and without biocrusts, and (d) these differences would decrease with increasing depth, were tested.

2. Materials and methods

2.1. Study sites

The study was carried out in the Alagol rangelands of Turkmen Sahra around the lowlands of Alagol Lake, 60 km north of Gorgan, Golestan province, Northern Iran (37°15′–37°23′ N and 54°33′–54°39′ E) (Fig. 1). The plain of Turkmen Sahra is connected in the north with deserts of Karakum in Turkmenistan, in the east with the Kopet-Dag Mountains occurring on the border between Turkmenistan and Iran, in the south with the Hyrcanian)Caspian) mixed forests, and in the west with the Caspian Sea lowland wetlands. In general, the study area is physiographically a plateau with a 3–5% general slope and 8% side slope, at an altitude of 15 to 47 m above sea level. The Alagol rangelands in Turkmen Sahra comprise loess hills, and it is thought that the soil forming these hills originated in the Qara Qum (Karakum) Plain in Turkmenistan, from where it was transported by wind to Iran (Kehl et al., 2005). The soil type at our study sites is classified as loam, mixed, superactive, thermic Sodic Haplogypsides and the soil texture is loam (United States Department of Agriculture USDA, 2010). The soils are fertile, but vulnerable to erosion, land degradation, and desertification (Kehl et al., 2005). Compared to lowland soil, the soils in the study area (Fig. 3F) are well drained, with medium infiltration rates, and a greater depth to the water table. General properties of soil horizons at the study showed in Table 1 (Sarmadian, 1998).

The climate of the study area is continental and dry, with a mean annual precipitation of 273 mm, the highest rainfall occurring in January and February, and the lowest in July and August (Iranian Meteorological Organization (IRIMO). The mean annual temperature is 13.1 °C, the absolute max. and min. temperatures being 42.8 °C and −5.36 °C respectively. Annual potential evaporation is 1700 mm.

2.2. Vascular vegetation and types of biological soil crusts

There have only been two previous studies of the vascular vegetation of Alagol rangelands (Jafari et al., 2004; Mirdeylami et al., 2012). According to these studies, the vascular vegetation in our study area is dominated by Poaceae (15 species), Asteraceae (12 species), Fabaceae (8 species), Lamiaceae (8 species) and Brassicaceae (4 species). Some important vascular plants and biocrust lichens are listed in (Supplementary Information). Total ground cover was estimated at about 34%, of which 9% and 6% were mosses and lichens, respectively (Jafari et al., 2004). The collected biocrusts species specimens have been deposited in the Iranian Cryptogamic Herbarium (ICH) at the Iranian Research Organization for Science and Technology.

2.3. Soil sampling and soil properties determination

In order to investigate the effects of biocrusts on soil physicochemical characteristics, sampling was performed in four separate areas 1 km apart with similar climate, geology and topography. In each of the study areas, soils with plants and biocrusts were sampled from randomly established 100 m transects at four locations every 25 m, i.e. 25 m, 50 m, 75 m, 100 m at two depths (0–5 & 5–15 cm). A bare site adjacent to each of these four sampling locations was sampled (as shown in Fig. 3C and E). In all, 64 locations (4 sites × 4 sampling locations × 2 depths) were investigated.

In the laboratory, the soil samples were air-dried and sieved to 2 mm. Subsamples were mixed in a mechanical agate mortar to obtain the 0.5 mm particle size necessary for the determination of organic carbon and exchangeable cations. The following physical properties were determined: particle size distribution by the hydrometer method (Glendon, 1986); available water content (AWC) by difference between water content retained at 33 KPa and 1500 KPa, using a Richard's pressure-membrane extractor (Dane and Hopmans, 1986); wet aggregate stability (WAS) using the drop test (Kemper and Rosenau, 1986); aggregate size distribution using the geometric mean diameter (GMD) of the aggregates (Kemper and Rosenau, 1986), bulk density (ρb) (Black and Hartge, 1986) and infiltration using a double ring infiltrometer (Reynolds et al., 1986).

The following physicochemical properties were determined: soil acidity (pH) (McLean, 1982), calcium carbonate (Nelson, 1982) and electrical conductivity (EC) (Rhoades, 1982), as well as exchangeable sodium (Rhoades, 1982), calcium (Lanyon and Heald, 1982), and magnesium (Lanyon and Heald, 1982).

The following chemical properties were also analysed: soil organic carbon (SOC) (Nelson and Sommers, 1996); soil total nitrogen (STN) (Bremner and Mulvaney, 1982); available phosphorus (Olsen and Sommers, 1982), available potassium (Knudsen et al., 1982), extractable zinc (Baker and Amacher, 1982), extractable copper (Baker and Amacher, 1982), iron (Olson and Roscoe, 1982) and manganese (Robert and William, 1982).

2.4. Statistical analysis

To test the effects of biocrusts on soil properties, we applied nested design and the data were analyzed in SAS (Version 9.1.3). Nested design was used since there was one variable with two or more subvariables; this design tested significant variation among groups, subgroups within groups. The comparison of means among the areas with or without biocrusts was undertaken by Duncan's multiple range test ($P < 0.05$).

3. Results

3.1. Effects of biological soil crusts on soil physical properties

The presence of biocrusts had a significant effect on most of the physical properties measured (Table 2); there was no significant difference in clay, silt or sand content among the depths or the soil surface cover types, but bulk density in the surface (0–5 cm) was lower in the biocrusted soils (1.29 ± 0.06; Table 2).

Available water content was higher in surface soils under biocrusts, followed by subsurface soils under biocrusts. Both of these values were higher than those of soils without biocrusts, which did not differ from each other at either depth. Surface soil aggregates beneath biocrusts