Aeolian Research 13 (2014) 81–89

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Inferring the impact of rainfall gradient on biocrusts' developmental stage and thus on soil physical structures in sand dunes

Eli Zaady[a,*], Itzhak Katra[b], Hezi Yizhaq[c,d], Shai Kinast[c], Yosef Ashkenazy[c]

[a] Department of Natural Resources, Agricultural Research Organization, Gilat Research Center, Mobile Post Negev 2, 85280, Israel
[b] Department of Geography and Environmental Development, Ben-Gurion University of the Negev, Israel
[c] Department of Solar Energy and Environmental Physics, Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede-Boqer Campus, Israel
[d] The Dead Sea and Arava Science Center, Tamar Regional Council, Israel

ARTICLE INFO

Article history:
Received 13 August 2013
Revised 2 April 2014
Accepted 2 April 2014
Available online 8 May 2014

Keywords:
Soil crust
Sand dune
Soil hydrology
Chlorophyll
Polysaccharides
Infiltration rates

ABSTRACT

The aims of this study were to investigate the impact of biological soil crusts' (biocrust) developmental stage on soil physical structures in sand dunes under two different rainfall regimes. It was hypothesized that biocrust's developmental stage and function, as affected by the aridity level, may impact soil surface properties, pedogenesis and hydrology. Bio-physiological parameters of the biocrust (polysaccharide, protein and chlorophyll contents) were studied for the determination of its developmental stage. The soil physical surface properties that were measured included the surface breaking pressure and granulometry. Hydrological measurements included the infiltration rate and soil moisture regime in deep layers and structure granulometry. These measurements were taken over two years, in scraped top soil surfaces and in homogeneous sandy dunes, and were compared with natural biocrust surfaces. Higher precipitation at the northern site, with a more advanced developmental stage of the natural biocrust compared to the southern site, has affected the structure granulometry by increasing the cohesive fractions of clay and very-fine silt within the soil surface layer. Higher infiltration rates and soil moisture (%) below the biocrust were obtained with the cyanobacterial crust at the dry southern site. Biocrust controls water infiltration into the soil sub-surface by affecting the surface penetrability. The infiltration controlled by the crust was inversed to the rainfall gradient. The novelty of this study is that by characterizing the bio-physiological parameters of biocrusts as affected by aridity levels, it is possible to imitate climate change scenarios on soil moisture in specific sites.

1. Introduction

The transition zone between arid and semi-arid areas is sensitive to precipitation and may be used to model the potential impact of climate change on community structure (Siegal et al., 2013). The effect of climatic change in arid and semi-arid areas is not limited to climatic factors. It is often accompanied by a parallel change in the properties of the soil surface (Almog and Yair, 2007). Desert ecosystems are subject to short wet intervals and long periods of drought. Shifts in moisture availability in the soil environment and water movement in these systems are critical processes affecting the biochemical and physical properties of the soil surface (Schlesinger et al., 1996). In sandy environments, climatic changes can be also associated with winds that expose roots, bury vegetation and biological soil crusts (biocrust), reduce vegetation cover and increase evapotranspiration.

Biocrusts are the common component that covers the soil surface in vast areas arid and semi-arid lands worldwide (Belnap and Lange, 2003; West, 1990). The developmental stage of biocrust is susceptible to climate changes. The annual rainfall affects the successional stage of the biocrust, which is reflected by the biocrust composition. This cryptogamic, biogenic or microphytic crust community varies markedly from typical two mm thick, relatively homogeneous cyanobacterial crusts to complex crust communities about 15 mm thick (Zaady et al., 1997). The biocrust and its components are considered to be "ecosystem engineers," as their formation plays an important ecological role in key processes in the development of dry ecosystems (Belnap and Lange, 2003; Zaady et al., 2013). In the successional pathway of the crust communities, the pioneers in colonizing the soil surface after disturbances are the cyanobacteria, which are followed by green algae, mosses and lichens (Eldridge and Greene, 1994; Johansen, 1993; West,

* Corresponding author. Tel.: +972 (0)8 992 8658; fax: +972 8 992 6485.
E-mail addresses: zaadye@volcani.agri.gov.il (E. Zaady), katra@bgu.ac.il (I. Katra), yiyeh@bgu.ac.il (H. Yizhaq), shaikinast@gmail.com (S. Kinast), ashkena@bgu.ac.il (Y. Ashkenazy).

http://dx.doi.org/10.1016/j.aeolia.2014.04.002
1875-9637/

1990; Zaady et al., 2000). Different factors can modify successional pathways from the same initial state of the system. Physical influences, such as soil structure, granulometry and soil types, radiation intensity, and topographic traits influence the successional pathways and the soil crust community (Veste et al., 2001, 2011). For example, the slope aspect affects water availability and soil moisture in arid systems (Katra et al., 2007a,b; Yair, 1990; Yair et al., 2008). When physical conditions are similar, disturbances are the key factors that determine a specific successional stage (Yair and Verrecchia, 2002; Zaady et al., 1997, 2000; Zaady and Offer, 2010).

Sand dune areas are considered to be dry habitats and are characterized by their extremely low particle cohesion. The sand grains on the surface are available for transport by wind speeds greater than 6 m/s (Tsoar et al., 2008; Tsoar and Møller, 1986). Sand dunes can be stabilized due to colonization by filamentous cyanobacteria, which may constitute a prominent crust (Danin, 1996). The results of the interactions between sand, vegetation and biocrust that lead to dune stabilization are not yet fully understood (Kinast et al., 2013). Since crust organisms have the ability to activate their photosynthetic systems for short periods, even at low levels of water availability, such as fog, dew and atmospheric water vapor (Lange et al., 1992), they are often the first organisms to colonize sand dune environments. The polysaccharides that are produced by these cyanobacteria and by soil algae (Bertocchi et al., 1990; Mager and Thomas, 2011) form a mucilaginous sheath on the soil surface that lightly binds the soil surface particles (Baily et al., 1973; Metting and Rayburn, 1983; Schulten, 1985). Thus, the polysaccharides play an essential role in sand stabilization, in limiting water infiltration and in significantly reducing wind erosion (Eldridge and Kinnell, 1997; Neuman et al., 1996). A high moisture holding capacity, typical of polysaccharides, enhances further crust development and facilitates colonization by other organisms, such as surface cyanobacteria, soil algae, mosses and lichens. Furthermore, it has been suggested that the fine material, accumulated by biocrust activities, increases the soil depth by adhering to the soil particles and plays a key factor in gluing to the materials (e.g., polysaccharides) secreted by the cyanobacteria (Belnap and Lange, 2003; Veste et al., 2011; Zaady et al., 2013; Zaady and Offer, 2010). It has been shown that biocrust may limit infiltration (Yair et al., 2011). Different assessments exist on how biocrusts affect infiltration, soil moisture and overland runoff generation (Belnap, 2006). It was reported, in sandy dune areas that are stabilized and semi-stabilized, that the biological topsoil crust plays an important role in the local water regime, as it affects rainwater infiltration, runoff generation and the spatial redistribution of water resources and, consequently, leads to spatial differences in the soil water regime (Yair, 1990, 2001; Almog and Yair, 2007; Yair et al., 2011). Biocrust may limit infiltration (Yair et al., 2011). Runoff and soil moisture data, obtained from hydrological investigations in a sand dune area, highlight the important role of the crusted soil surface (Yair, 1990). Several research projects conducted at the Nizzana research site, located in the southern part of the sandy area in the northeastern Negev Desert, have reported on the important role that biocrusts play in the hydrological and spatial redistribution of water resources within a dune system. Yair et al. (2011) showed that the composition of the topsoil crust is highly dependent on the local soil moisture regime. The wettest area is characterized by a moss-dominated crust, while the driest area is characterized by the predominance of cyanobacteria (Kidron et al., 2003; Almog and Yair, 2007).

It was hypothesized that biocrusts' successional stage may be affected by aridity levels and that it is reflected by soil surface properties (e.g., granulometry, the content of the cohesive soil particles of very-fine silt and clay fractions <10 μm, soil surface hardness, water permeability and soil moisture). Moreover, it is possible to infer the developmental stage of the biocrust based on the aridity level (Zaady et al., 2010).

The objectives of this study were: (1) To determine whether the developmental stage of the biocrust, as influenced by aridity levels, affects soil surface properties, pedogenesis and hydrology in sand dunes. (2) To show the differences between treatments within each site. (3) To examine whether measurements at two ends of the rainfall gradient in a sand dune area (arid and semi-arid) can imitate climate change scenarios of biocrusts' successional impact on soil moisture in specific sites. We used a multidisciplinary approach by combining bio-physiological, physical surface properties and hydrological measurements to address the objectives.

The innovation of this work is that by studying the features of the bio-physiological parameters of biocrusts as influenced by aridity levels, it is possible to predict climate change scenarios on soil moisture in specific sites.

2. Methods and materials

2.1. Study area

In the northern Sinai Peninsula (Sinai-Negev erg), the Negev (Israeli) dune field is dominated by semi-stable (active crest) and stable vegetated linear dunes, while the Egyptian side is characterized by active sand dunes due to increased anthropogenic activities, mainly the trampling of goat herds (Karnieli and Tsoar, 1995; Tsoar, 2008). The Negev sand dunes are mostly composed of quartz with very few other minerals, mostly calcite, magnetite, hematite and other silicates (Almagor, 2002).

The stabilization of the northern Sinai Israeli sand dunes is mainly attributed to biocrust and, to a lesser degree, to vegetation (Roskin et al., 2012; Siegal et al., 2013). The climate in the research area is arid to semi-arid; within a range of 25–30-km, the precipitation rate varies from 150 mm/yr in the north to 70 mm/yr in the south (Breckle et al., 2008; Karnieli and Tsoar, 1995; Tsoar, 2008; Tsoar and Møller, 1986). The composition of the biocrust in the area varies from south to north. In the south, the biocrust is composed primarily of cyanobacteria, while moving northward with the rainfall gradient, green algae, mosses and soil lichens also appear. The cyanobacteria are represented by *Microcoleus sociatus*, *Calotris perientina* and *Nostoc* sp.; the Chlorophytes are represented by *Chlorococcum* sp. and *Stichococcus* sp. (Lange et al., 1992; Zaady et al., 2000); mosses are represented by *Bryum* sp., and lichens are represented by *Collema* spp., *Fulgensia fulgens*, *Squamarina cartilaginea*, *S. lentigera* and *Diploschistes diacapsis* (Budel and Veste, 2008; Veste et al., 2011).

The northwestern Negev dune field (about 30 km^2) can be subdivided into several sections, based on its geological structure, the wadis that traverse the area and the morphology of the sand dunes (Siegal et al., 2013; Tsoar et al., 2008, Fig. 1). The dunes' height and wavelength decrease as a function of precipitation (and hence stabilization) when moving northward with the rainfall gradient from the more arid site to the semi-arid site (see Table 1). The winter season begins in November–December and ends in April–May. However, the span of this season can vary by about two months.

2.2. Experimental sites

Soil surface sampling commenced in the northernmost semi-arid site (150–170 mm/yr average annual precipitation, 31°9′9″N, 34°18′30″E) and continued in the southernmost arid site (70–90 mm/yr, 30°56′07.24″N, 34°23′39.86″E) (Fig. 1), along the Israel–Egypt border of the northwestern Negev. The distance between the sites was about 30 km. Plots were located at the