Journal of Hydrology 508 (2014) 128–136

Contents lists available at ScienceDirect

Journal of Hydrology

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

The negative effect of biocrusts upon annual-plant growth on sand dunes during extreme droughts

Giora J. Kidron *

Institute of Earth Sciences, The Hebrew University, Givat Ram Campus, Jerusalem 91904, Israel

ARTICLE INFO

Article history:
Received 19 June 2013
Received in revised form 15 October 2013
Accepted 26 October 2013
Available online 4 November 2013
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of Alon Rimmer, Associate Editor

Keywords:
Available water
Sand
Biological soil crust
Microbiotic crust
Evaporation
Annual plants

SUMMARY

Following recent findings that biocrusts (known also as biological soil crusts) enhance the evaporation of the underlying soil in the dune field in the Negev Desert (P = 95 mm), an attempt is made to evaluate the effect of biocrust on plant germination and growth during drought years. Periodical (mainly weekly) moisture measurements of the upper 30 cm layer were conducted at 5 habitats of formerly defined biocrust types and at 4 non-crusted habitats during 2010/11 and 2011/12 (extreme drought years with 30.4 and 35.2 mm, respectively). At the end of each growing season, the species composition, cover and biomass of the annual plants was measured. While only limited germination and annual-plant maturation took place in the crusted habitats during 2011/12, no germination was recorded at the crusted habitats during 2010/11, explained by enhanced evaporation due to lower albedo of the biocrusts. In contrast, annual-plant germination and maturation took place at the non-crusted habitats during both years. Contrary to the common view that regards sand dunes as infertile and hostile for plant growth while highlighting the positive role of biocrusts on plants, the current findings indicate that as far as annual plant productivity is concerned, the non-crusted dune may serve as a fertility belt for annuals during extreme drought years.

1. Introduction

Abounding in arid and semi-arid regions, biocrusts, known also as biological soil crusts or microbiotic crusts, play an important role in stabilizing the surface (van den Ancker et al., 1985; McKenna Neuman et al., 1996; Zhang et al., 2006; Jia et al., 2012) and in providing carbon (Lange et al., 1992) and nitrogen (Mayland and McIntosh, 1966; Evans and Lange, 2001) to the ecosystem. They also play a role in pedogenesis (Fischer et al., 2010) and in hydrological processes and thus in water redistribution (Kidron, 1999). This may be especially important in regions where water is the main limiting factor for plant growth (Noy-Meir, 1973).

Despite their importance in controlling water and nutrient fluxes, little is known regarding their effect on vascular plants. While they were shown to facilitate plant growth by providing surface stability (Kadmon and Leschner, 1994), water (Kidron, 1999), and nitrogen (Mayland and McIntosh, 1966), their effect on community dynamics is relatively scarce. Most research has focused on the effect of biocrusts upon germination. In most cases, a negative effect on plant germination was detected, which was attributed to their firm and compacted seal (Eckert et al., 1986; Prasse and Bornkamm, 2000; Eldridge and Simpson, 2002; Serpe et al., 2006; Su et al., 2007). Yet, not all results were conclusive (Hawkes, 2004; Escudero et al., 2007; Cortina et al. 2010; Godínez-Alvarez et al., 2012). Likewise, there have also been contradictory results regarding the effect of plants on biocrusts. While some researchers report that mulch, shading, and high-density grass may impede biocrust establishment (Dunne, 1989; Breen and Lévesque, 2008; Read et al., 2008), this may not be necessarily the case in arid regions with low shrub cover where shading may result in high under-canopy surface wetness duration and subsequently in high-biomass biocrusts (Kidron and Vonshak, 2012).

Following their role in surface stabilization, biocrusts were regarded as positively contributing to plant establishment in sand dunes (Li et al., 2005; Su et al., 2007). This was also the case in the Hallamish dune field in western Negev Desert (Kadmon and Leschner, 1994; Tielbörger, 1997). Yet, given recent findings concerning the effect of biocrust on the surface temperatures and evaporation in the Hallamish dune field (Kidron and Tal, 2012), and given the frequent droughts in the Negev, studying the effect of biocrust on the soil moisture and vascular plants becomes highly relevant.

While the effect of droughts on vascular plants was extensively studied (Parra et al., 2010; Pang et al., 2011; Vanaja et al., 2011), and biocrusts in the Negev were claimed to impede infiltration for perennial plants (Almog and Yair, 2007; Veste et al., 2011; Siegal et al., 2013), the effect of biocrusts on annual plants during

* Tel.: + 972 544 967 271; fax: +972 2 566 2581.
E-mail address: kidron@vms.huji.ac.il

0022-1694/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jhydrol.2013.10.045

droughts was not investigated. This may be especially important following the high evaporation rates that were recorded at crusted surfaces at the Nizzana research station (NRS) at the Hallamish dune field. Explained by their low albedo of 17.3–23.3 (from the most xeric and thin biocrust to the thickest and mesic biocrust) in comparison to 33.0 of sand when wet, sand overlaid by biocrusts was shown to loose its moisture much faster than sand without biocrust (Kidron and Tal, 2012). The biocrusts were thus shown to have a negative effect on the moisture regime of the upper soil layer.

The hypothesis that the effect of biocrust on increasing evaporation may be especially crucial to plants during drought years (when precipitation is particularly limited) was examined. The effect of biocrust may be especially pronounced on annuals which only rely on rainfall during the relevant growing period. The goal of the current research is to explore the effect of biocrusts upon the subsurface water content and upon the growth of annual plants during drought years.

2. Materials and methods

2.1. The research site

The research was conducted at the Nizzana research station (NRS) in the Hallamish dune field in the western Negev Desert, Israel (34°23′E, 30°56′N). Long-term mean of precipitation is 95 mm falling mainly during November to March (Rosenan and Gilad, 1985). Average annual temperature is 20 °C; it is 26 °C during the hottest month of July and 8 °C during the coldest month of January. Annual potential evaporation is ~2600 mm (Evenari, 1981).

Longitudinal dunes, trending west–east, characterize the Hallamish dune field. The dunes, up to 20 m high are separated by wide 50–200 m) interdunes. The crest and the top part of most dunes are characterized by loose mobile sand (96–98% with the remaining material being silt and clay), and lack biocrusts. Biocrusts cover however the lower flanks of the dunes and the sandy interdunes, where wind velocity is low enough to facilitate their establishment.

A total of 5 types of biocrusts were defined in NRS, covering >90% of the surface. Four biocrusts were cyanobacteria dominated (crusts A–D), and one moss-dominated (crust E). Whereas the most xeric crust, crust A, extends over the south-facing slopes and over the interdunes, crusts B–E extend over the north-facing slopes (Fig. 1). On a low and therefore crusted (and hence stabilized) dune, crust B extends along the upper slope section, followed by crust C at the mid-upper slope, crust D at the midslope, and crust E that extends over the interface between the footslopes of the north-facing slope and the interdune. The biocrusts significantly differed in biomass components (chlorophyll, protein, carbohydrates) (Kidron et al., 2010). Some of the biocrust properties are shown in Table 1.

Sparse cover of perennial plants, <1–2%, mainly of *Stipagrostis scoparia* (Trin. & Rupr.) De Wint and *Heliotrópium digynum* (Forssk.) C. Chr. characterizes the mobile crest sections. Higher cover of perennial plants, 5–10%, characterizes the semi-stable sections of the non-crusted surfaces with shrubs such as *Artemisia monosperma* Del., *Retama raetam* (Forssk.) Webb, *Noaea mucoronata* (Forssk.) Asch. & Schw. and *Cornulaca monocantha* Delile predominating (Danin, 1996; Tielbörger, 1997). Crusted surfaces, with 10–20% plant cover, are mainly inhabited by *Cornulaca monocantha* and *Noea micoronata*, many of which dried out following the frequent droughts in the early 2000s. The shrubs are accompanied by annual plants. The predominating annuals are *Erucaria rostrata* (Viv.) Taeckh. & Boulos, *Cutandia memphitica* (Spreng.) Bth., *Picris radicáta* (Forssk.) Less., *Plantago* spp., *Rúmex píctus* Forsk., *Neurada procumbens* L., *Senecio glaucus* L., and *Ifloga spicata* (Forssk.) Sch. Bip. (Danin, 1996).

2.2. Methodology

For the evaluation of the soil moisture content, 9 pairs of stations were demarcated along a north–south transect, previously used for studying the hydrological characteristics of the different habitats (Kidron et al., 2003). They included all 5 biocrusts mentioned above, i.e., crusts A–E (in agreement to their spatial distribution; see Kidron et al., 2010), and 4 non-crusted habitats with loose sand: the mobile south-facing (MS) and north-facing (MN) slopes of the crest, a flat semi-stable section at the crest (S) and the interface between a steep and a moderate north-facing slope which received the addition of subsurface water (SN). Some of the surface properties are shown in Table 1. A schematic cross-section of the transect is shown in Fig. 1.

Rain was measured with a tipping bucket rain recorder in the Kadesh Barnea meteorological station, 4.5 km south of our research site (http://www.meteo-tech.co.il/negev/negev_daily.asp). In addition, 4 rain gauges were placed in the research site. Periodical measurements (mostly on a weekly basis, with a total of 13 and 17 samplings during the rainy period of 2010/11 and 2011/12, respectively) were manually carried out for soil moisture content in each pair of stations. Samples of approximately 20–30 g were collected into glass flasks at 5 cm intervals from the upper 30 cm of the soil profile, which according to previous examination hosts >90% of all roots of the annual plants (Kidron, unpub.). The flasks were tightly closed and brought to a nearby lab for measurements. They were weighed, oven-dried at 105 °C until reaching a constant weight and then weighed again.

The volumetric water content was determined following the equation:

$$Wv = Ww * Db/Dw$$

Where Wv (cm^3/cm^3) is the volumetric water content, Ww (g) the gravimetric water content, Db (g/cm^3) is the soil bulk density and Dw (g/cm^3) is the water density (≈1).

Yet, in order to determine the actual moisture that may potentially be available to the plants, i.e., the available water content (AWC), the actual volumetric water content was subtracted from the wilting-point water content (determined by pressure plates;

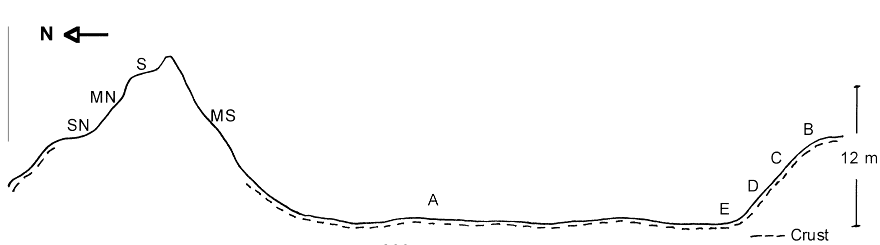

Fig. 1. A schematic cross section of the transect across all habitats.