Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Drought effect on biocrust resilience: High-speed winds result in crust burial and crust rupture and flaking

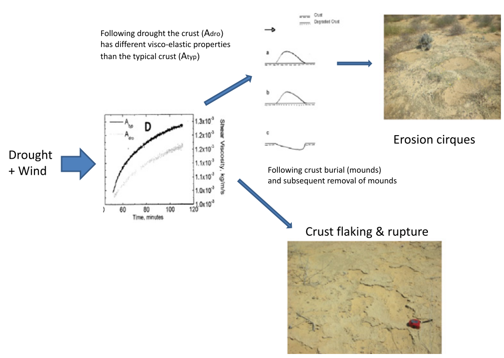
Giora J Kidron [a,*], Wang Ying [b], Abraham Starinsky [a], Moshe Herzberg [b]

[a] *Institute of Earth Sciences, The Hebrew University, Givat Ram Campus, Jerusalem 91904, Israel*
[b] *Department of Desalination and Water Treatment, Zuckerberg Institute for Water Research, Ben-Gurion University of the Negev, Sede Boqer Campus, 84990, Israel*

HIGHLIGHTS

- Two mechanisms for biocrust degradation are reported: burial and rupture.
- Crust rupture and flaking took place following two years of consecutive droughts.
- This is the first report on crust rupture under natural conditions.
- Modification of the crust's extracellular polymeric substances explains rupture.
- The hazardous effects that frequent droughts on ecosystem stability are highlighted.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 July 2016
Received in revised form 31 October 2016
Accepted 2 November 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Crust erosion
Negev Desert
Resilience
Vulnerability
Wind power

ABSTRACT

Once established, biocrusts (known also as biological soil crusts or microbiotic crusts) are thought to be relatively resilient to wind erosion, with crust burial being considered as the main mechanism responsible for crust death. Thus far, to the best of our knowledge, crust flaking and rupture under natural conditions were not reported. We report herein a two-year study during two severe drought years (2010 — 2012) in a dunefield in the Negev Desert during which in addition to crust burial, crust rupture and flaking also took place. As for crust burial, it took place under sand sheets or coppice dunes (mounds). Subsequent removal of the coppice dunes by wind resulted in crust disintegration and erosion of the formerly buried crust and the formation of patches devoid of crusts termed herein 'erosion cirques'. As for crust flaking and rupture, it is explained by a large change in the properties of the extracellular polymeric substances (EPS) composing the crust. The EPS adherence and viscoelastic properties were monitored using a quartz crystal microbalance with dissipation monitoring (QCD-M) technology. EPS adherence and viscoelastic properties deduced from the QCM-D experiments suggest that crust coherence and elasticity, mediated by the EPS, were affected by droughts. Although crust flaking affected up to 25% of the interdunal surface, it is suggested that with continuous rain shortage, further crust flaking is likely to take place under continuous drought-driven dry surface conditions. This positive feedback mechanism, during which initially eroded crusts trigger additional crust erosion, may have severe consequences on the structure and function of drought-prone ecosystems, and may endanger the stability of dunefields, causing dust storms, triggering dune encroachment and declining air quality.

* Corresponding author.
E-mail addresses: gkidron@post.tau.ac.il (G.J. Kidron), xianrenqiu1113@outlook.com (W. Ying), stari@mail.huji.ac.il (A. Starinsky), Herzberg@bgu.ac.il (M. Herzberg).

http://dx.doi.org/10.1016/j.scitotenv.2016.11.016
0048-9697/© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Biocrusts (known also as biological soil crusts or microbiotic crusts), which are comprised of cyanobacteria, green algae, lichens, mosses, bacteria and fungi in different proportions, abound in drylands. Biocrusts play an important role in arid and semiarid regions, providing organic C and N (Mayland and McIntosh, 1966; Lange et al., 1992; Hawkes, 2003; Veluci et al., 2006), and may increase (Kidron, 1999) or decrease runoff yield (Williams et al., 1995). However, as far as sandy ecosystems are concerned, the main contribution of biocrusts may be their role as a stabilizing agent (McKenna Neuman et al., 1996; Sweeney et al., 2011). Due to their dense network of filaments and to extracellular polymeric substances (EPS) secretion of sheaths and slime (Mazor et al., 1996; Kidron et al., 1999; Tisdall et al., 2012), the crusts were found to effectively stabilize the surface, impeding the drift and migration of soil particles by wind (McKenna Neuman et al., 1996; Belnap and Gillette, 1998) and water (Kidron, 2001). While high-speed wind may impede crust establishment (Kidron et al., 2009; Kidron and Zohar, 2014), once established, the crusts are perceived as having high resilience to wind (Ash and Wasson, 1983; McKenna Neuman et al., 1996; Marticorena et al., 1997; Littmann, 1997; Zhang et al., 2006; Thomas and Dougill, 2007). With high regeneration rates that require only ~5–6 years (Kidron et al., 2008), the crusts may be considered as effective agents for dune stabilization. Yet, burial under loose sand deleteriously impacts the role of crusts as a stabilizing agent (Booth, 1941; Jia et al., 2008), affecting crust physiology and growth (Jia et al., 2012).

The high resilience of crusts to wind erosion was thus far reported from wind tunnel experiments (McKenna Neuman et al., 1996; McKenna Neuman and Maxwell, 1999; Rice and McEwan, 2002; O'Brian and McKenna Neuman, 2012). Crusts were reported to be resilient to wind velocities of 25 m s^{-1} (Zhang et al., 2006; Pan et al., 2008) even following 8 h-long exposure to such velocities (Hu et al., 2002). Alternatively, biocrusts were found to be vulnerable to disturbance, such as trampling (during which some of the crust is destroyed; see Zhang et al., 2006), or prolonged sand grain bombardment (Rice and McEwan, 2002; Langston and McKenna-Neuman, 2005; O'Brian and McKenna Neuman, 2012). Thick crusts (McKenna Neuman and Maxwell, 1999; Hu et al., 2002) or high-biomass crusts (Hu et al., 2002) were however found to substantially increase their resilience (but see also McKenna Neuman et al. (1996) and Xie et al. (2007)). This was also the case in the Negev, where crusts were found to drastically reduce sand erosion and deposition (Kidron and Zohar, 2014), being responsible, as found in the USA (McLaurin et al., 2011), for the reduction of dust emission and air pollution.

Nevertheless, while being vulnerable to sand burial, which under non-grazed conditions may only affect small sections of the dunefield (Kidron, 1999), large-scale burial and/or crust rupture due to changing environmental conditions may constitute a high risk of instability in the ecosystem. Ecosystem instability may be accelerated during droughts (during which annual precipitation is <0.75 of the long-term mean; see Jain et al., 2009; Pandey et al., 2010), which in addition to low precipitation may also be characterized by potent and erosive windstorms (Bogle et al., 2015).

Ecosystem instability was also recorded in the Hallamish dunefield in the western Negev Desert (Fig. 1) following frequent droughts (Kidron, 2015). In comparison to the long-term mean of 95 mm for 1960–1990 (Rosenan and Gilad, 1985), average annual precipitation during 1996–2012 in NRS was only 61.5 mm, implying that 10 out of the last 17 years (i.e., 58.8%) were drought years (Kidron, 2015). With biocrusts covering all the sandy interdunes and the middle and lower parts of the dunes (being only absent from the dune crest) (Kidron et al., 2010), changes in environmental conditions may be hazardous.

Nevertheless, during extensive research, which took place between 1989 and 1995, crusts exhibited high resilience to sand burial. Patches of buried crusts (usually <1 m-diameter and under 3–10 cm-high sand) were noted only following occasional high-speed winds, being confined to a narrow belt of ~5 m at the interface between the uncrusted crest and the crusted slopes (Kidron, 1999). High resilience was however noted by the crusted surfaces of the bottom slopes and interdunes, which were partially covered by 1–2 mm sand only during extreme windstorms. This was the case during the exceptionally strong windstorm of 9–11.2.1992 (with hourly average speeds of up to 24 m s^{-1}) causing severe damage to greenhouses at the edge of the dunefield, ~5 km south (Kidron and Yair, 2001). Being accompanied by rain (as is often the case during the passage of cold frontal rainstorms; see Enzel et al., 2008) and occasionally by runoff, the thin veneer of sand (<2 mm) that covered the wet crusted slope following the windstorm did not accumulate on the ground and therefore did not result in crust burial and death. It was washed away by runoff (Kidron and Yair, 2001).

Sand accumulation leading to crust burial may however be triggered by droughts, during which surface moisture is too low to effectively prevent sand drift from the uncrusted mobile crests, thus leading to crust burial at the crusted slopes and interdune. This was evidenced during

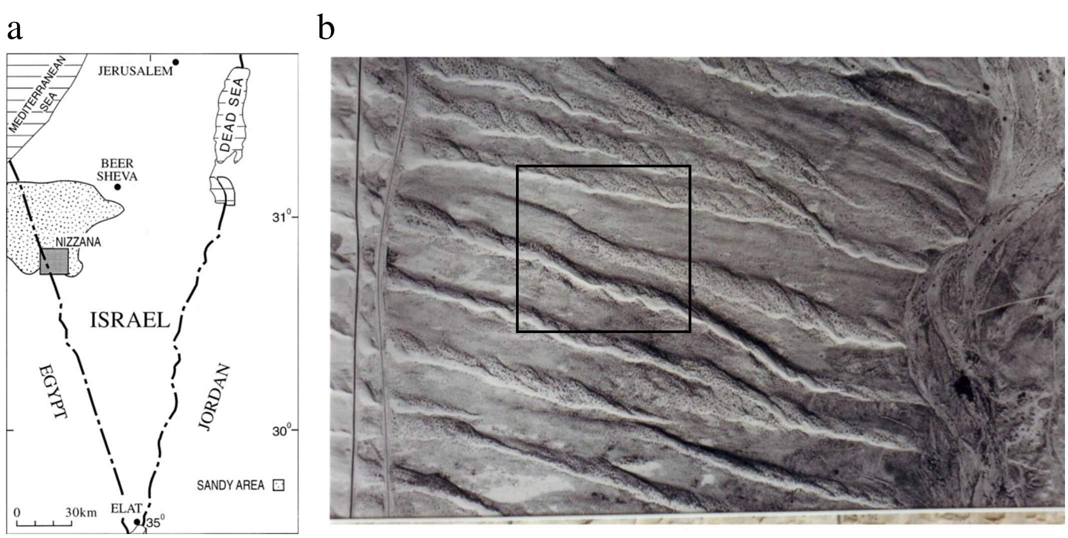


Fig. 1. Location (a) and air photograph (b) of the research site. Note the border roads (left of photograph) and the dry river bed of Nahal Nizzana (right of photograph) at both sides of the longtitudinal dunes of the Hallamish dunefield. The black frame marks the Nizzana research site.

Please cite this article as: Kidron, G.J., et al., Drought effect on biocrust resilience: High-speed winds result in crust burial and crust rupture and flaking, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.11.016