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Millimeter-scale microrelief affecting runoff yield over microbiotic crust in the Negev Desert

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Abstract

The negative effect of microrelief upon runoff yield, explained by the increase in water storage and the slowdown in flow velocity, is a known phenomenon. However, research concerning surface roughness hitherto focused on decimeter- or centimeter-scale microrelief. Owing to the heterogeneous character of many natural plots, the effect of centimeter-scale microrelief was mainly shown under controlled sprinkling experiments, whereas no data was yet made available concerning the possible effect of a millimeter-scale microrelief upon runoff yield under natural field conditions.

When runoff yield was measured over crusted (i.e., surfaces covered by 1–3 mm of cyanobacterial crust) and scalped 2–6 m^2 plots at the Hallamish dune field (Negev Desert, Israel) during 5 winter seasons (1990–1995), no runoff was generated from the scalped plots during the first year following scalping while meagre quantities were received during the second year. Nevertheless, during the third season and onward, runoff yield at the scalped plots was consistently and significantly higher than that of the crusted (control) plots and this was so albeit the fact that the crust chlorophyll content of the scalped plots during the third season was as low as half the amount of the crusted plots. These findings appeared to contradict previous findings that showed the existence of a positive linear relationship between the crust chlorophyll content and runoff yield. The apparent contradiction was explained by the differences in the plot microrelief, indicating that minute differences, even of a millimeter-scale, may greatly affect runoff yield and thus may compensate for lower crust chlorophyll content. Surface smoothness, which characterizes many of the arid zones, may thus explain, at least partially, the high runoff yield obtained in deserts.

Keywords: Runoff; Microbiotic crust; Microrelief; Surface roughness; Negev Desert

1. Introduction

Runoff may play an important role within ecosystems, affecting hydrological, pedological, geomorphological and ecological processes. It is more so in arid regions where high volume floods may cause substantial destruction to infrastructures such as roads and bridges. Runoff in arid regions is also important due to its contribution to water redistribution and the consequent runon zones that may increase opportunities for plant germination and increase species diversity. Therefore, any factor that may affect runoff yield may have important implications.

Numerous factors may affect runoff yield including rain intensity and duration, the inherent infiltration capacity of the soil, antecedent moisture, surface properties and vegetation cover (Hillel and Tadmor, 1962; Blackburn, 1975; Scoging, 1989). Surface properties that affect runoff include the formation of a mineral crust (Tarchitzky et al., 1984; Zhang and Miller, 1996), mulch (Kramer and Meyer, 1969), microbiotic crust (Kidron and Yair, 1997), stoniness (Poesen and Ingelmo-Sanchez, 1992; Cerda, 2001), and the surface microrelief. While some researchers claim that surface roughness may enhance runoff through flow concentration (Luk and Morgan, 1981; Sole-Benet et al., 1997), most researchers agree that an increase in surface roughness will result in an increase in friction drag (Sanchez and Wood, 1987) and the consequent decrease in flow velocity (Dunne

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and Dietrich, 1980; Abrahams and Parsons, 1991). The consequent decrease in runoff and sediment yield led therefore to the development of special agricultural practices such as contour cultivation (Hudson, 1989), furrow diking, and pitting (Unger, 1996). These decimeter- and centimeter-scale ridges and depressions were designed to decrease runoff velocity and to increase surface detention and storage.

Although measurements of surface microrelief reported in the literature are usually confined to decimeter- or centimeter-scale microrelief, sheet flow may not usually exceed a few millimeters in thickness (Dunne and Dietrich, 1980; Dunkerley, 2003). Thus, through the microrelief impact upon friction drag and flow velocity, and through its impact upon the increase in surface detention, millimeter-scale microrelief may play an important role in explaining runoff yield.

Minute differences in the surface microrelief characterized the crusted surfaces of the Hallamish dune field in the Negev Desert, Israel. Following medium and high intensity rain spells of 9–12 mm h^{-1}, these crusted surfaces, having cyanobacteria- and moss-dominated crusts yielded runoff (Kidron and Yair, 1997). On the other hand, the meager amounts of silt and clay within the parent material did not facilitate the formation of a physical crust and consequently no runoff was generated from the non-crusted dune summit (Kidron, 1999). When analyzed, a positive linear relationship between the crust chlorophyll content and runoff was found on cyanobacterial crusts (Kidron et al., 2003). Yet, when plots with moss-dominated crust were also included in the analysis, a second degree polynomial equation characterized the relationship, explained by the relatively low ratio of exopolysacchrides in the moss-dominated crust and by its higher surface roughness (Kidron et al., 2003). Whereas a comparison between cyanobacterial crusts and moss-dominated crust may fail to detect the role of each variable in runoff generation due to the very different nature of the crust organisms, a comparison of plots having cyanobacterial crusts but differing in their microrelief may assist in the evaluation of the microrelief role in runoff generation. Evaluating the role of microrelief in runoff generation over the crusted dune surfaces was the goal of the current research.

2. Material and methods

The research is located in the Nizzana research station at the Hallamish dune field, western Negev Desert, Israel (Fig. 1). The area receives approximately 95 mm of precipitation a year, falling during the winter months of November to April (Rosenan and Gilad, 1985). The site is comprised of 10 to 20 m high longitudinal dunes, trending west–east, separated by 100 to 200 m wide interdunes. The dunes and interdunes are composed of medium to coarse sand with 50–80% of the sand grains being between 250–500 μm and fines content (silt and clay) ranging between 2–6% with clay being for most cases <1%. Salinity is low with electrical conductivity ranging between 100–200 μS cm^{-1}. Likewise, organic matter is low and is mainly composed of microbiotic

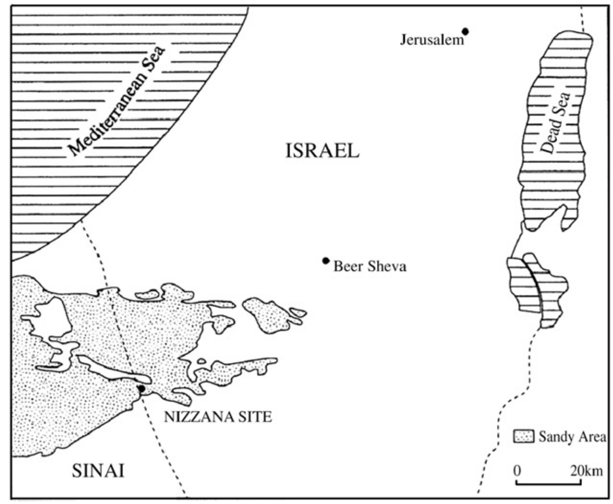

Fig. 1. Location of research site.

crust. Indeed, excluding the dune summits that are devoid of crust and therefore characterized by loose and mobile sand, most of the remaining dune field is covered by microbiotic crusts and therefore is stabilized. Apart from small areas (~5%) that are covered by moss-dominated crusts and are characterized by relatively high organic matter of 2–3%, all other crusted surfaces are covered by cyanobacterial crusts having an organic matter content of 0.5–0.9% (Karnieli et al., 1999). Chlorophyll *a* content of the crusts ranges between 15–20 mg m^{-2} in the interdune and the southern aspect to 20–60 mg m^{-2} in the northern aspect.

The current research took place during 1990–1995. Two pairs of runoff plots were demarcated during 1990. The plots were demarcated on surfaces that did not have old stems or any visible organic matter other than the microbiotic crust (Fig. 2a, b). The plots were demarcated with 0.5 mm thick, 20 cm high metal sheets, inserted 10 cm into the sand, at two northern aspects (Table 1). One plot in each pair was scalped (P1s, P2s), whereas the remaining plot was left intact and served as a control (P1c, P2c). The plots were scalped by using sharp metal plate, 20 × 20 × 0.05 cm, that was carefully inserted underneath the crust (Fig. 2c). Once removed, the surface was reexamined and remaining pieces were removed using a spatula. In this way, as little inoculate as possible remained in the plots (Fig. 2c).

The plots were equipped with 50 l containers. During the winter and following each rainstorm, runoff was measured in each plot. During the growing season (in intervals of 3–6 weeks), the annual cover was visually monitored and 6–12 samples were collected for chlorophyll determination. Monitoring of the annual cover was carried out by measuring the diameter of the annuals close to the plot margin and multiplying the average size by the number of seedlings. As for the chlorophyll, 12–24 one cm^2 samples, 1 cm deep, were taken during the growing season and summer and measured in accordance with the method outlined by Vollenweider (1969). In order to avoid, as much as possible,