LIVESTOCK REDISTRIBUTE RUNOFF AND SEDIMENTS IN SEMI-ARID RANGELAND AREAS

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ABSTRACT

Semi-arid areas where grazing is the main land use exhibit a "three-phase-mosaic" pattern of dominant surface patches: shrubs, trampling routes, and intershrub areas. This pattern differs from the "two-phase mosaic" seen in grazing-free semi-arid areas. The patches might create a positive feedback process in which enhanced infiltration beneath shrubs minimizes overland flow from under their canopies, thereby strengthening the sink/source mechanism by which overland flow generated between shrubs rapidly infiltrates into the soil beneath them, where it deposits soil particles, litter, nutrients and organic matter, thereby enhancing infiltration by changing the local microtopography, and improving soil properties. To analyze sink/source relationships among the patches in grazed areas in rangelands of the semi-arid northern Negev region of Israel we constructed small runoff plots, 0.25–1.0 m^2 in area, of five types: shrub (*Sarcopoterium spinosum*)~~ (SH)~~; intershrub~~ (IS)~~; and route~~ (RU)~~; route/shrub combination~~ (RS)~~; and intershrub/shrub combination~~ (SI)~~. The shrubs always occupied the downslope part of the plot. Overland flow and sediment deposits were measured in all plots during 2007/8 and 2008/9. The combined plots ~~SI and SR~~ yielded much less overland flow and sediments than intershrub~~IS~~, ~~RU ~~routes and ~~SH~~shrub ones, indicating that the shrubs absorbed almost all the yields of the upper part of their plots. The shrubs generated less runoff and sediments than routes and intershrubs; runoff flows from the routes and intershrubs were similar; sediment yield was highest in the intershrubs. Thus, runoff yield exhibited a two-phase mosaic pattern, and sediment yield, i.e., soil erosion, a three-phase mosaic pattern.

1. INTRODUCTION

Grazing has been seen as one of the key causative factors of desertification in semi-arid ecosystems (Cerdà et al., 2010), because of the increases in soil erosion and runoff discharge, caused, in turn, by exhaustion of the vegetation and the encroachment of bushy plants (Angassa, 2012). This has led to use of enclosure to control grazing intensity (Mekuria and Aynekulu, 2013), and to control of stocking rates (Vetter and Bond, 2012). However, land management is now being seen as the main cause of land degradation and desertification (Bennet et al., 2012), and grazing more as a solution than a problem, if the management is appropriate (Álvarez-Martínez et al., 2013).~~ 2014). to avoid wildfires, which are the cause of intense soil erosion (Lasanta and Cerdà, 2005).~~ Some authors found that grazing is a sustainable and necessary land use (Shang et al., 2014) to maintain a healthy environment (Jones et al., 2014; Mulale et al., 2014, Carreiras et al., 2014). Grazing can involve positive impacts on ecosystems such as increasing the total bud bank density and stimulating plant growth (Qian et al., 2014), managing the biomass, restoring pastures invaded by shrubs (Álvarez-Martínez et al., 2013), to avoid wildfires, which are the cause of intense soil erosion (Lasanta and Cerdà, 2005). Arid and semi-arid environments are characterized by a non-uniform ground surface cover, comprising various components such as vegetation, bare soil, exposed bedrock, rock fragments, and crusts (Cerdà, 1997; Lavee et al., 1998; Calvo-Cases et al., 2003; Arnau-Rosalén et al., 2008; Dickie and Parsons, 2012; Kakemboey al., 2012; Kröpfl et al., 2013). Each component constitutes a separate microenvironment, with its own pedological, hydrological, ecological and geomorphological behavior (Yair and Lavee, 1985; Li and Sarah, 2003), driven by complex interactions and feedbacks (Sarah, 2003). The spatial distribution of the microenvironments is a main key, on the one hand, to understanding the various eco-geomorphic processes that shape the landscape, on the other hand, and to explaining the complex hydrology of semi-arid environments. The effect of the patchy distribution of vegetation on hillslope hydrology and soil erosion found to be more pronounced than that of the hillslope position (Cerdà, 1998a). The strongly coupled ecological-hydrological system of vegetation and open areas is of great importance in analyzing these processes, because of the patchy distribution within the landscape of essential resources such as water, soil particles, organic matter, and nutrients (Bergkamp, 1998). This patchiness creates a complex matrix of source-sink microenvironments (Bergkamp, 1998; Puigdefabregas et al., 1999), in which the shrub patches act as sinks for water and water-borne resources, and patches of bare soil act as sources (Yair and Lavee, 1985; Cerdà, 1998a; Lavee et al., 1998; Li and Sarah, 2003; Calvo-Cases et al., 2003). This matrix supports a positive-feedback process: the enhanced infiltration beneath shrub patches minimizes overland flow under their canopies and thereby strengthens the sink/source mechanism by which overland flow generated in the bare-soil patches rapidly infiltrates into the soil beneath the shrubs (Bergkamp, 1998; Lavee et al., 1998; Sarah, 2002; Calvo-Cases et al., 2003; Ben-Shmuel, 2005), where it deposits soil particles, litter, nutrients and organic matter which, in turn, enhance the infiltration rate in the shrub patches by changing their micro-topography (Stavi et al., 2008a) and improving the texture, structure and aggregate stability, porosity, fertility and chemical composition of their soil (Puigdefabregas and Sanchez, 1996; Cerdà, 1998d; Rietkerk et al., 2002; Calvo- Cases et al., 2003). Patchiness of plants, which affects the soil aggregate stability, found to be one of the key factors of reinforcement of the eco-geomorphic system (Cerdà, 1998d). Thus, patchiness represents a self-organized hillslope system, which maximizes harvesting of runoff, minimizes losses of sediment and nutrients, and thereby retains water and soil resources within the system (Shachak et al., 1998; Tongway and Ludwig, 2003).The spatial distribution of these two patch types was designated as a two-phase mosaic by many authors (e.g., Bergkamp, 1998; Eddy et al., 1999; Galle et al., 1999; Ludwig et al., 1999). This pattern has been shown to have significant consequences for the water-infiltration characteristics of semi-arid hillslopes (Abrahams and Parsons, 1991) because the vegetation in these environments is sustained by overland flow from bare soil in the open spaces between shrubs (Puigdefabregas and Sanchez, 1996). On hillslopes subject to grazing, as in the northern Negev region of Israel, the mosaic pattern is more complicated: the open spaces between shrubs comprise two components, i.e., areas with herbaceous vegetation, separated by trampling routes that support no vegetation. Therefore, the clearly visible routes were considered to differ from the remainder of the intershrub area with regard to pedohydrological characteristics, and were designated as a third type of surface cover, in addition to the shrubs and herbaceous areas; grazing induces a modification of semi-arid rangelands from two-phase to three-phase mosaic geo-ecosystems (Sarah, 2009; Stavi et al., 2012).

Conclusions regarding the redistribution of runoff and sediments in rangelands were based on theoretical deductions derived from pedohydrological properties such as hydraulic conductivity (Bromley et al., 1997), infiltration capacity (Eldridge et al., 2000), soil moisture (Sarah, 2002; Katra et al., 2007) and organic matter contents (Sarah, 2006), penetration resistance (Manzano and Navar, 2000; Stavi et al., 2008b), vegetation properties (Puigdefabregas et al., 1998; Shachak et al., 1998; Golodets and Boeken, 2006), or simulation models (Ludwig et al., 1999; Puigdefabregas et al., 1999).

Many studies have dealt with the causes and processes of runoff generation and sediment movement in semi-arid environments (e.g., Yair and Lavee, 1981, 1985; Cerda, 1998a,b, c; Lavee et al., 1998; Calvo-Cases et al., 2003; Arnau-Rosalén et al., 2008). These processes include leakage of water and resources from the ecosystem (Shachak et al., 1998), and preservation of water and resources by retention in shrub or vegetation patches on hillslopes (Bromley et al., 1997; Bergkamp, 1998; Puigdefabregas et al., 1998, 1999; Ludwig et al., 1999). Most of these studies have been based on rainfall simulation experiments in the field (Yair and Lavee, 1981, 1985; Lavee et al., 1991; Parsons et al., 1992; Bergkamp, 1998; Cerda, 1998c; Calvo-Cases et al., 2003; Arnau-Rosalén et al., 2008) or in the laboratory (Bryan, 2000); others have been based on visual estimations (Bromley et al., 1997; Bergkamp, 1998). Furthermore, studies on runoff and sedimentation processes under natural rainfall conditions were conducted on medium and relatively large scales, i.e., part or all of the hillslope or catchment (e.g., Puigdefabregas et al., 1998, 1999; Bergkamp, 1998; Parsons et al., 1992); virtually all the studies based on small-scale runoff plots in the field used simulated rainfall and resembled one another in the means of application: they involved rainfall intensity of 50-55 mm h^{-1} during 45–60 min (Imeson et al., 1996; Cerdà, 1998b; Calvo-Cases et al., 2003; Arnau-Rosalén et al., 2008).

In spite of the numerous studies cited above, in a survey of hydrological and erosion data obtained under natural or simulated rainfall on limestone landscapes in various Mediterranean environments in the last 15 years, Calvo-Cases et al. (2003) found that, although several different environmental factors- climate, topography, lithology, soil surface cover, land use- were addressed, only a few studies took grazing into account.

The objectives of the present paper were: to confirm the role of shrub (*Sarcopoterium spinosum*) patches as sinks for water (rainfall and overland flows) and sediments, and the role of the open areas between shrubs (routes and the remaining intershrub patches) as sources under natural rainfall, in rangelands of the northern Negev in Israel; and to determine to what extent the patches differ in their overland flow generation and sediment production in this area. It was hypothesized that: the three types of surface cover/patches would differ in their responses to rainfall; the routes and the shrubs, respectively, would yield the highest and lowest outputs of overland flow and sediments, with those from the intershrubs falling between them.

2. MATERIALS AND METHODS

2.1. Study Area

The research was conducted in the Goral Hills in the northern Negev region of Israel (Fig. 1). This is a hilly, semi-arid area, lying 350–500 m, with mean annual precipitation of 300 mm, most of which falls during the cold season – October–May (Perevolotsky and Landau, 1988; Osem et al., 2002). The winter is cold and rainy, with average daily temperature in January, the coldest month, of 10^{o} C; the summer is hot and dry, with average daily temperature in August, the hottest month, of 25^{o} C. Relative humidity ranges between 51% in May and 68% in January (Bitan and Rubin, 1991; Bar'am, 1996). The lithology is chalk and limestone of the Eocene (Ravikovich, 1981, cited in Osem et al., 2002). The soil, Leptosols, is shallow, generally not deeper than 20 and 40 cm in open spaces between shrubs and under shrubs, respectively, except in rock fissures. The color of dry soil is pale brown (7.5 YR 6/3) and that of wet soil is brown (7.5 YR 4/3); the texture, on average, is clay-loamy in which the primary particle-size distribution is 20–30% clay, 40–50% silt and 30% sand (Zwikel et al., 2007). The cation-exchange capacity (CEC) is 16 meq per 100 g in the uppermost (0–5 cm) layer, and the cation distribution in this layer (in meq per 100 g) is Ca^{2+}, 12.9; Mg^{2+}, 0.5; K^{+}, 1.3; and Na^{+}, 0.7. The dominant clay type is smectite, and the stone content is about 15–30% (Dan and Koyumdjisky, 1979; Zwikel et al., 2007). The mean gradient of the hillslopes is 15°. The study area, like many other semi-arid areas of the Old World, has been grazed by flocks of sheep and goats since prehistoric times, i.e., for 5000–8000 years, therefore the vegetation mainly comprises grazing-tolerant species (Noy-Meir and Seligman, 1987). The vegetation physiognomy comprises sparse shrubland containing a patchy distribution of vegetation, biological crusts, exposed bedrock, and bare soil. The vegetation includes: (a) dwarf shrubs, mainly *Sarcopoterium spinosum, Coridothymus capitatus*, and *Thymelaea hirsute*; (b) perennial grasses and forbs, mainly *Asphodelus ramosus and Poa bulbosa*; and (c) annual herbaceous vegetation (Osem et al., 2002). The research area is occupied by flock trampling routes, shrubs, and intershrub spaces, which cover 22, 17, and 61%, respectively, of the landscape (Stavi et al., 2008b).

Fig. 1.

2.2. Field work

Observations in the research area have revealed three main types of surface cover: shrubs, flock trampling routes, and intershrub areas (Fig. 2).

Fig. 2.

In order to confirm the sink/source relations among the dominant types of surface cover, several different small runoff plots, of area ranging from 0.25 to 1.0 m^2, were constructed on the central parts (backslopes) of south-facing hillslopes: three of them contained shrub, *Sarcopoterium spinosum* (SH), intershrub (IS), and route (RU), respectively; two contained combinations of route and shrub (~~RS~~SR), and of intershrub patches and shrubs (SI), with the shrub(s) always located in the lower part of the plot (Fig. 3). For each type of plot three replicates were constructed.

Fig. 3.

The plots were bounded by concrete walls, 3–5 cm high, pegged to the ground and embedded 2 cm into the soil. A pipe, through which water was collected into a bucket embedded in the ground, was fitted at the topographically lower end of each plot.

Each bucket had a capacity of 10.5 L, to ensure collection of the whole runoff yield from 'bare ground' plots in heavy storms. In order to avoid loss of water in small rain events, small,1-L receivers were mounted inside the buckets just beneath the entry pipes, and whenever the volume of collected runoff water did not exceed the capacity of the small receivers, they alone were taken to the laboratory. After each rain event, the buckets containing runoff water and sediment were replaced in the field, and were taken to the laboratory for determination of the gross weight of the runoff and sediment yields.

The amount of rainfall was measured by four small rain-gauges mounted perpendicularly to the slope, near the runoff plots, in order to measure the actual rainfall in the area.

2.3. Laboratory work and statistical analysis

The total yields of runoff and sediment were determined by weighing, on the assumption that 1 mL of water weighs 1 g. The sediment yield was calculated by oven-drying the runoff water for 24 h at 105° C, and weighing the sediments left in the vessel. The sediment yield (g) was then subtracted from the total weight of (runoff water plus sediment), in order to determine the runoff volume (mL). Statistical analyses were applied with EXCEL and SAS software. The runoff and sediment data were subjected to Duncan’s non-parametric Multiple-Range test (Duncan, 1955) at the $p < 0.05$ level of significance, to determine significant differences between microenvironments.

3. RESULTS

3.1. Rainfall

In the 2007/8 and 2008/9 rainy seasons the rainfall amounts reached 178.8 and 143.2 mm, respectively, which are below the annual average in the research area, i.e., 300 mm. In each season, most of the rain fell in January and February, i.e., more than 50% of the season's total rainfall fell during these two months (Fig. 4).

Fig. 4.

3.2. Runoff yield

~~During~~ In the two consecutive winters, 2007/8 and 2008/9, ~~it was found that~~ the minimal amount of rainfall, ~~that~~ which ~~could~~ generated runoff in the ~~research~~ study area was ~~about~~ ca 4 mm (Table 1). Among the 17 rain events in the season of 2007/8, overland flow was generated in only 10 events, and in the winter of 2008/9, runoff was generated in seven out of nine rain events. ~~In both years, the minimal rainfall amount for the generation of runoff in the research area was ca. 4 mm (Table 1).~~

Tab. 1

Figure 5 shows the mean annual specific runoff yield (the volume of runoff per square meter) at the various plots for each year. For each plot the annual mean was based on the results of three replicates. It can be seen that the runoff generated in the various plots showed similar trends in all years: the combined plots – SI, SR and SH – yielded significantly less runoff than IS and RU, which yielded similar amounts to one another.

Fig. 5.

3.3. Sediment Yield

Figure 6 shows the mean annual specific sediment yields (the weight of sediments per square meter) at the various plots for each year. Those of IS and RU were significantly higher than those of the combined plots, SI, SR and SH.

Among the various patch types: the highest specific sediment yield was obtained in IS, that in RU was lower, although not significantly so, and that in SH was significantly the lowest. This trend was observed in each year.

Fig. 6.

4. DISCUSSION

4.1. Patch functions

A clear difference was apparent between the ~~RU~~ route and the ~~IS~~ intershrub plots, on the one hand, and the combined plots – ~~SI~~shrub+intershrub, and ~~RS~~ shrub+route – on the other hand (Figs 5, 6). The ~~IS~~ intershrub plot yielded about 7 and 48 times more specific runoff and sediment deposits, respectively, than the combined ~~SI~~ shrub+intershrub plot;

and the ~~RU~~ route plot yielded 6 and 28 times more specific runoff and sediment deposits, respectively, than the combined ~~RS~~ shrub+route plot. These relations were attributed primarily to the presence of shrubs in the combined plots: runoff and sediments that developed in the "bare" soil reached the shrubs, where a great part of them were trapped by the shrub and settled in situ, while the remaining – minor – part continued to flow. This ability of the shrubs to collect runoff resulted from the combined effects of several processes that enhance infiltration: the shrub canopy and the litter beneath it soften direct raindrop impact on the soil and dissipate their kinetic energy, thereby preventing formation of mechanical crusts and, in turn, enhancing infiltration (Rostango and del Valle, 1988; Dunkerley and Brown, 1995; Bromley et al., 1997). Moreover, shrubs act as a physical barrier that moderates overland flow velocity and continuity (Sanchez and Puigdefabregas, 1994); consequently they trap soil and litter (Bergkamp, 1998; Shachak et al., 1998), forming soil mounds (Rostango and del Valle., 1988; Parsons et al., 1992) and thereby changing the surface microtopography, and soil texture and bulk density (Van Haveren, 1983; Trimble and Mendel 1995; Stavi et al., 2008b, 2009). The combined physical, chemical and biological effects of shrub roots (Archer et al., 2002) and soil biological activity (Garner and Steinberger, 1989) improve soil organic matter content and structure (Oades, 1984; Sarah and Rodeh, 2004; Sarah, 2006), which reduces bulk density even more (Dunkerley and Brown, 1995), and creates macropores, in which water flows vertically at relative high rates (Bromley et al., 1997). Furthermore, in the study area the deepest soil was found beneath the shrubs. In addition, in a study conducted in a rangeland in the same region, Stavi et al. (2008a) suggested that loose sediments reached the upward-facing part of the downhill-located shrub, reduce the surface gradient and increase soil porosity, with the result that runoff velocity is reduced and continuity is interrupted, both of which enhance infiltration capacity (Bergkamp, 1998; Shachak et al., 1998).

The actual yields of runoff and sediments that were obtained in the present study confirm the role of shrubs as a sink for water and sediments, and that of the open areas between shrubs, i.e., intershrubs and routes, as sources.

4.2. Importance of the function of trampling routes and intershrubs as sources

The yields of runoff and sediments from the various patches in semi-arid study site spring from the combined effects of herbivory and trampling, on the one hand (Golodets and Boeken, 2006), and nutrient addition in the forms of urine and dung, on the other hand (McNaughton, 1979).

4.2.1 Runoff yield

The relative differences in runoff between the ~~IS~~ intershrub and ~~SH~~shrub, and between ~~RU~~ route and ~~SH~~ shrub were similar in each of the years: ~~RU~~ route and ~~IS~~ intershrub yielded six times more runoff than the ~~SH~~shrub. These findings indicate the balance between favorable and unfavorable environmental conditions in the patches.

The loess soil of the study area, including that of the various patches, contains 20–30% clay (Ben-Hur et al., 1985; Zwikel et al., 2007) in which smectite is the dominant component (Shainberg et al., 1990). This soil is sensitive to physical and chemical disruption of aggregates and is subject to dispersion of clay particles, which clog the pores of the upper soil layer (Agassi et al., 1981; Shainberg et al., 1990). The ~~IS~~ intershrub patches are characterized by a dense cover of annual and perennial herbaceous vegetation (geophytes, grasses and forbs) and bare soil. The loess soil is partially compacted by sporadic trampling by livestock, with consequent mechanical formation of crust, which is commonly developed in this area. The trampling routes have the highest soil compaction and a sparse covering of herbaceous plants, which can be attributed directly to the impact of intense animal traffic: hoof action damages and detaches tissue from growing plants (Pande and Yamamoto, 2006), thereby reducing canopy and herbaceous cover, and increasing the exposure of bare soil. The animal trampling compacts the soil, thereby increasing soil bulk density (Schlesinger et al., 1990; Stavi et al., 2008a) and destroying the topsoil structure (Manzano and Navar, 2000), especially along flock trampling routes (Warren et al., 1996; Stavi et al., 2008b). These processes enhance subsequent rain splash and thereby increase mechanical crusting and surface sealing of the soil (Wilcox et al., 1988; Bari et al., 1993), which eventually reduces infiltration into the soil and promotes surface runoff (Manzano and Navar, 2000; Sarah, 2002) from the "no shrub" patches, i.e., ~~RU~~ route and ~~IS~~intershrub. Also, these patches vary in their inclination, which is lower in the ~~RU~~ route than in the ~~IS~~intershrub, at 4–6° and 13–15°, respectively (Stavi et al., 2008a), because of the animal trampling that smoothes the surface of the former (Nash et al., 2003, 2004).

On the one hand, the higher soil compaction and lower vegetation cover in the ~~RU~~ route tend to promote runoff but, on the other hand, their lower gradients tend to reduce it. In contrast, in the ~~IS~~ intershrub the runoff is influenced by the same factors acting in the opposite senses, i.e., lower soil compaction and higher vegetation cover tend to reduce runoff, whereas higher gradients tend to promote it. Thus, the balance between factors that promote runoff generation and those that reduce it is similar, therefore runoff yields in the ~~RU~~ route and ~~IS~~ intershrub were similar.

The similarity between the runoff yields, which indicates that there was no difference between the water contributions of the ~~RU~~ route and of the ~~IS~~intershrub, contradicts part of the hypothesis that: "the three types of surface cover/patches differ in their responses to rainfall". We found that only the ~~SH~~ shrub patch differed from the other two patches.

Observations during the two years of the present study showed that no runoff was contributed to the channel from the hillslopes. Kosovsky (1994) studied rainfall/runoff/infiltration processes in two low-order drainage basins, which are located in the present study area; he recorded no more than two stream flows in the basins during the winters of 1990/91 and 1991/92, when the annual rainfall was 266 and 376 mm, respectively. The differences between Kosovsky's (1994) study and the present one can be explained by the difference in the annual rainfall amount which affects runoff connectivity. The winters of the present study were dry (2007/08 and 2008/09 – annual rainfall of 179 and 143 mm, respectively. The runoff generated in the sources was dispersed and infiltrated beneath the shrub, thus, no connectivity of runoff sources occurred. In the wetter winters of Kosovsky's study large areas of the hillslope were saturated, caused an increase in runoff connectivity, thus and stream flows occurred. This means that in this semiarid area the existing spatial pattern of the main surface components expresses optimal efficiency in maintaining the hillslope ecosystem through dry years and wet years as well.

4.2.2 Sediment yield

In contrast to runoff, the relative differences in sediment yield between each of the two source patches and the sink patch were different. In both years the differences between the ~~IS~~ intershrub and ~~SH~~ shrub were higher than those between the route~~RU~~ and

~~SH~~shrub: by average factors of 16.9 and 9.8, respectively, in both years. As described above, the lower local gradients and greater soil compaction in the route~~RU~~ than in the intershrub~~IS~~ result in dense organization of soil particles, which reduces their vulnerability to shear stress and erosion. Such compaction prevents biological activity and thereby reduces the proneness of available sediments to erosion. This means that the intershrub~~IS~~ patches are the ones most susceptible to soil erosion and, therefore, they are the main providers of nutrients to shrubs, because they have a higher organic matter content than the routes (Stavi et al., 2008b)

The finding that the ~~RU~~ route yielded less sediments than the intershrub~~IS~~ contradicts the hypothesis presented in the Introduction, that: "the routes and the shrubs have highest and lowest outputs of overland flow and sediments, respectively, with those from the intershrubs falling between them".

4.3. Runoff – erosion relations

A comparison among the runoff/erosion ratios of the patches revealed that each millimeter of runoff eroded sediments at 3.4, 2.2, and 0.9 g/m^2 from the intershrub~~IS~~, route~~RU~~, and SH patches, respectively. Shrubs reduce soil runoff-driven erosion because of the combined effects of consolidation of soil aggregates – by roots, and high contents of organic matter and soil moisture – and the low energy of the runoff on the flattened microtopography. The erosive effect of runoff is weaker in the route~~RU~~ than in the intershrub~~IS~~ for the reasons described under "*The importance of the function of trampling routes and intershrubs as sources*". Therefore, the SH and route~~RU~~ patches exhibited pronounced self-regulation of erosion processes whereas the intershrub~~IS~~ did not.

On the one hand, the soil texture of the research site, especially the relatively low percentage of clay particles, leads to mechanical crust formation but, on the other hand, the clay percentage is not high enough for its cohesive forces to maintain aggregate stability. This effect is exacerbated by the high content of the highly dispersive smectite, which is the dominant clay particle type in loess soils in the study area. Thus, it cannot necessarily be concluded that similar findings, i.e., runoff and sediment yields, could be expected to occur in soils having other clay contents and/or types.

4.4. Runoff coefficient

Runoff coefficients (ratio between runoff and rainfall), at the scale of measurement, obtained in the present study were higher than those found in previous field studies: Cerdà (1988a) found a runoff coefficient of 0.12 in simulated rainfall experiments on a south-facing slope with underlying limestone in south-east Spain. Calvo-Cases et al. (2003) found a runoff coefficient of 0.16 in a calcareous site in a semi-arid environment with mean annual rainfall and temperature of 387 mm and 17.9 °C, respectively, and Puigdefabregas et al. (1999) found a runoff coefficient of 0.1 in a single 66-mm rain event in a mica-schist bedrock site in semi-arid environment with mean annual rainfall and temperature of 300 mm and 16 °C, respectively. In contrast, the ~~mean~~ annual runoff coefficients found in the present study reached 0.~~5~~ 4 and 0.45 in 2007/8 and 2008/9, respectively, in the ~~RU~~ route and intershrub~~IS~~ patches. The differences among the above findings could be attributed to ecological and physical differences among the sites – differences mostly in soil properties, especially texture, i.e., clay content and mineralogy, and in vegetation, surface gradient, rainfall intensity, ~~and~~ land use~~.~~ and plot size.

4.5. Land use practice

Over-exploitation of natural or seminatural rangeland areas by overgrazing and/or by using the shrubs as a fuel source will cause gradual homogenization of the ground surface, leading to increasing continuity of overland flow generation and soil erosion at the hillside scale. This means decreased functionality of the ecosystem.

Human activity causes changes of the soil cover and calls for new solutions to cope with these changes. New surfaces have appeared in most landscapes in many parts of the world because of the dramatic increases in road construction over the last few decades. Also, abandoned mines and abandoned agricultural areas present environmental problems because of increased soil erosion, the loss of large areas that have become unexploited, and for aesthetic reasons. Practical suggestions for reclamation of such areas included planting vegetation: Haigh et al. (2013) concluded that providing a loosened, lower-density, rooting substrate significantly improved both the growth and the survival rates of trees planted in compacted Welsh surface coal-mine spoils, and that trench planting was more effective than park- and garden-style pit planting, which, in turn, is more effective than forestry-style notch planting. Lee et al. (2013) showed that using a digger to drill holes for planting vegetation was a cost-effective revegetation technology for stabilizing road cuttings in southwest Korea; they indicated that erosion-control species, *Poa pratensis* L. and *Eragrostis curvula* (Schrad.) Nees survived and grew better than native woody species. Jimenez et al. (2013), in their research on embankments of a highway in Central Spain identified establishment of vegetation and promotion of soil formation as key restoration practices related to ecological processes. Jiménez et al. (2014) found that mulching treatments that were applied to seedlings had great influence on soil properties and on the field performance of afforested holm-oak seedlings (*Quercus ilex* L. subsp. *ballota* (Desf.) Samp.) in an abandoned agricultural field in SE Spain.

All the above practices include revegetation as a useful tool for reclamation of the above human-affected areas. The present findings support use of the plant/soil pattern as a possible practice for preventing runoff and soil erosion in road cuttings and abandoned mines in semi-arid areas, i.e., planning of revegetation according to the three-phase mosaic pattern. The patches of this pattern differ in their hydrological and erosion-related functions: the shrubs collect runoff and sediments from the intershrub and route areas of the upper hillslopes. In addition, the routes moderate the gradient of the road margins, and thereby reduce the intensity of runoff and erosion processes. More studies are needed to evaluate the effectiveness of this management pattern on the above-discussed areas. Such studies need to relate to such questions as: Is seeding of herbaceous plants in the intershrub areas necessary in all climatic regions and in all soils? What shape of shrub canopy or root density distribution will achieve the optimal effect in preventing runoff generation and in stabilizing the slope? For how long need active modification/control of soil structure continue? For example: can the soil beneath the shrubs be left to develop a natural soil structure, while the soil in the open areas is compacted in order to promote overland flow which supports the shrubs? Does the soil in the open areas need to be stabilized with amendments (such as PAM – polyacrylamide) and for how long, in order to moderate the potential for erosion processes and to enable successful germination and growth? What are the optimal distances between shrubs (sinks) and between routes (sources)? In addition, the financial costs of the above treatments need to be considered.

5. CONCLUSIONS

Under the environmental conditions that prevailed in the studied rangelands, i.e., moderately intense grazing by 800 livestock units on 800 ha, the shrubs absorbed almost all of the resources produced in the routes and intershrubs.

Similarly to a two-phase mosaic, a pattern was confirmed for the runoff yield only, i.e., the only difference found was that between the shrubs, on the one hand, and the open spaces, routes, and intershrubs, on the other hand, with no differences between the latter two patches. However, erosion processes showed a "three-phase-mosaic" pattern in which a considerable part of sediments were eroded from the intershrubs, a smaller part from the routes, and, conspicuously, the least from the shrubs.

It is not necessarily concluded that similar findings, i.e., patterns of runoff and sediment yields, could be expected to occur in soils having other different clay content and/or types, and in rainier years.

The intershrub patches are the ones most susceptible to soil erosion and, therefore, they are the main providers of nutrients to shrubs.

The routes play an important role in ecosystem functioning by influencing the spatial redistribution of resources at the patch scale. Such non-trophic effects can be regarded as the actions of an ecosystem engineer, i.e., an organism that regulates the productivity of other organisms by controlling their resource supply or by modifying their habitat.

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Table 1: Rainfall, runoff and sediment events in the various plots, winters of 2007/8 and 2008/9. SH=Shrub; IS=Intershrub; RU=Route; SI=Intershrub+Shrub; SR=Route+Shrub.

Date	Rainfall	Specific runoff (mm)					Specific sediment (g/m^2)				
	(mm)	SH	IS	RU	SI	SR	SH	IS	RU	SI	SR
08/10/2007	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12/11/2007	4.2	0.0	0.1	0.3	0.0	0.0	0.0	0.9	3.0	0.0	0.0
22/11/2007	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23/11/2007	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
02/12/2007	8.2	0.4	3.2	3.7	0.4	0.3	0.1	21.5	29.4	0.4	0.9
20/12/2007	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21/12/2007	12.0	1.6	6.9	5.9	0.9	1.5	2.5	41.8	24.3	0.6	2.5
06/01/2008	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09/01/2008	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12/01/2008	10.6	0.0	0.5	0.6	0.0	0.0	0.0	0.6	0.8	0.0	0.0
24/01/2008	6.8	0.0	0.5	0.5	0.0	0.0	0.0	0.4	0.2	0.0	0.0
27/01/2008	12.6	1.2	4.8	4.8	0.4	0.4	1.7	6.0	5.8	0.2	0.3
28/01/2008	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31/01/2008	46.3	7.8	31.4	31.0	3.9	8.1	5.2	73.1	32.6	2.6	1.5
15/02/2008	28.2	0.9	14.7	14.3	1.2	1.3	1.0	56.1	26.4	0.5	0.7
20/02/2008	15.2	0.0	3.3	4.8	0.2	0.1	0.0	2.0	3.1	0.1	0.1
28/02/2008	12.7	0.2	8.7	7.9	0.7	0.3	0.3	54.3	34.1	0.5	0.4
30/10/2008	15.0	0.0	0.2	0.6	0.0	0.0	0.0	0.7	2.6	0.0	0.0
10/12/2008	5.0	0.0	1.5	2.1	0.0	0.1	0.0	8.4	19.6	0.0	0.3
28/12/2008	10.7	0.1	0.6	1.0	0.1	0.1	0.1	0.7	0.7	0.0	0.5
04/01/2009	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12/02/2009	36.8	8.0	19.3	19.8	6.7	5.6	27.9	211.3	91.7	7.2	5.2
18/02/2009	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22/02/2009	16.7	0.9	8.9	9.9	1.1	1.0	0.9	27.6	20.3	0.8	0.6
02/03/2009	36.5	0.3	24.4	25.9	2.2	3.7	0.0	181.1	111.1	1.0	1.8
25/03/2009	13.5	0.2	4.0	4.1	0.8	0.2	0.3	7.7	5.7	0.5	0.1

מעוצב:גופן: 12 נק', גופן עבור עברית ושפות אחרות: 12 נק'

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מעוצב:עצירות טאב: 1.02 ס"מ, שמאל

מעוצב טבלה

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מעוצב:גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

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מעוצב:גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

מעוצב:גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

מעוצב:גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

מעוצב:גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

מעוצב [1] ...

מעוצב [2] ...

מעוצב [3] ...

מעוצב [4] ...

מעוצב [5] ...

מעוצב [6] ...

מעוצב [7] ...

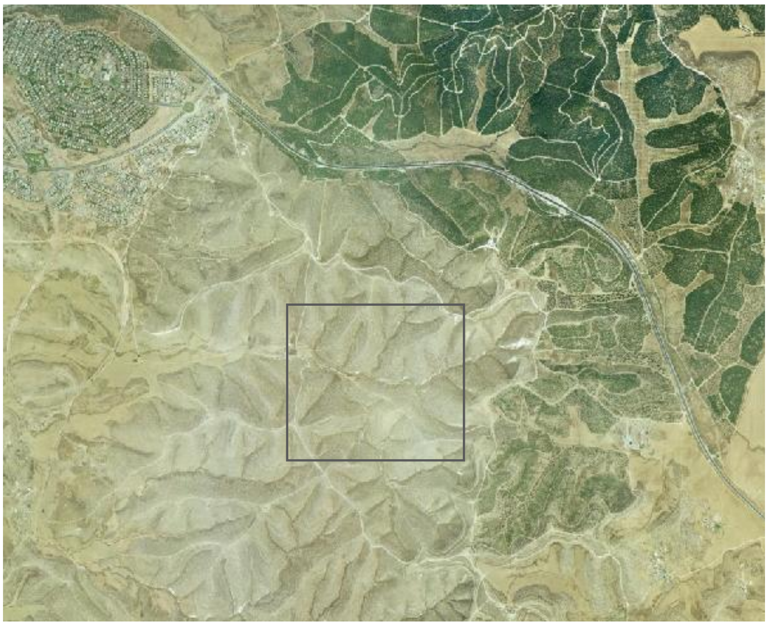
מעוצב [8] ...

מעוצב [9] ...

מעוצב [10] ...

מעוצב [11] ...

מעוצב [12] ...



~~Fig. 1. Aerial view of the research area.~~

מעוצב:גופן: (ברירת מחדל) +כותרות
עבריות, 12 נק', גופן עבור עברית ושפות
אחרות: +כותרות עבריות, 12 נק'

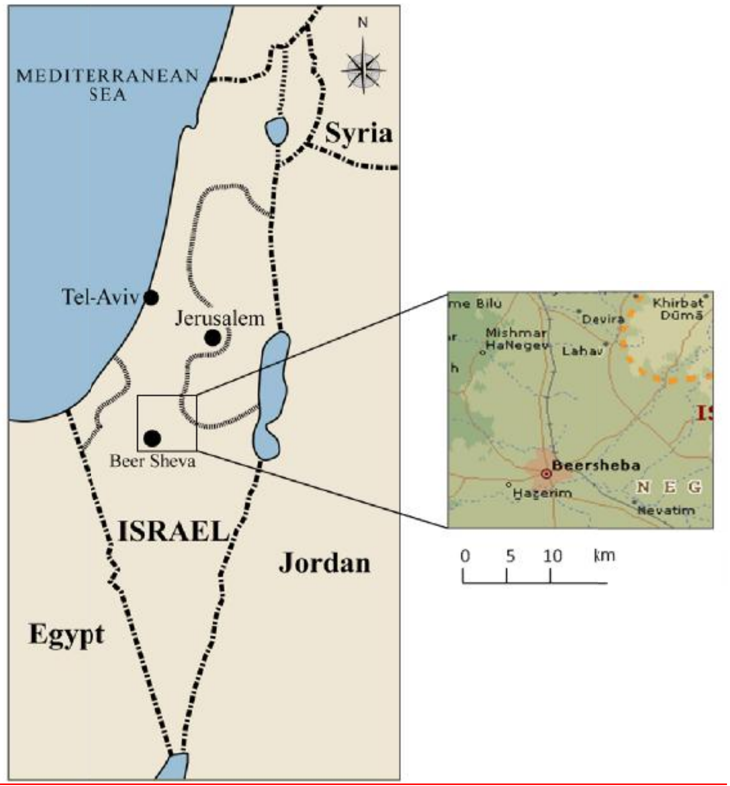


Fig. 1. Map of Israel, showing the study region.

Fig. 2. Three main types of surface cover in the research site.

Fig. 3. Small runoff plots. A- Shrub (SH); B- Intershrub area (IS); C-Trampling route (RU); D- Intershrub area + shrub (~~IS~~SI); E- Route + shrub (~~RS~~SR). (February 2008).

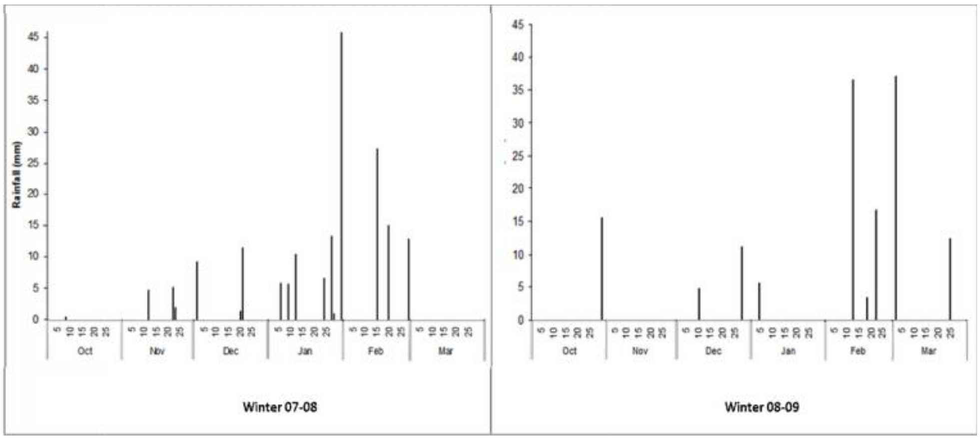


Fig. 4. Rainfall (mm) distribution in 2007/8 and 2008/9.

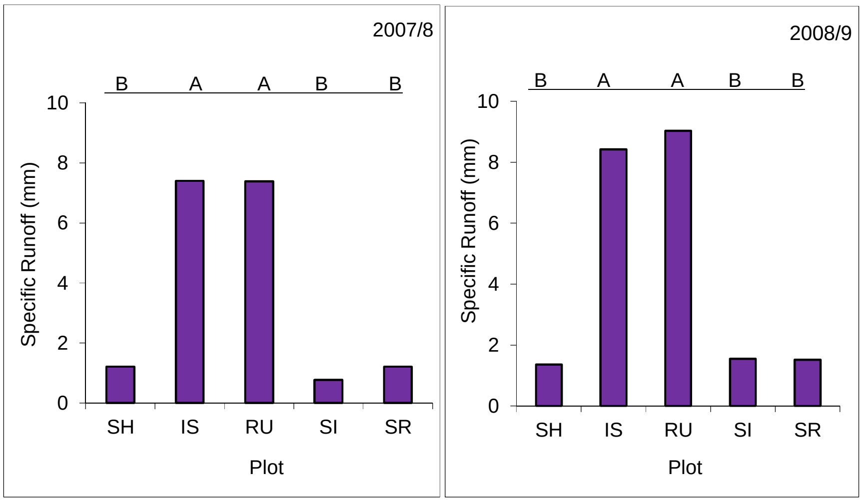


Fig. 5. Runoff yield in the various plots; winter seasons 2007/8 and 2008/9.

מעוצב:רגיל

SH=Shrub; IS=Intershrub; RU=Route; SI=Intershrub+Shrub; SR=Route+Shrub.

מעוצב:גופן: (ברירת מחדל) +גוף, 11 נק', מודגש, גופן עבור עברית ושפות אחרות: +גוף עברי, 11 נק', מודגש

Each value represents the mean of three replicates. For each year, means marked with different letters differ at $P < 0.05$.

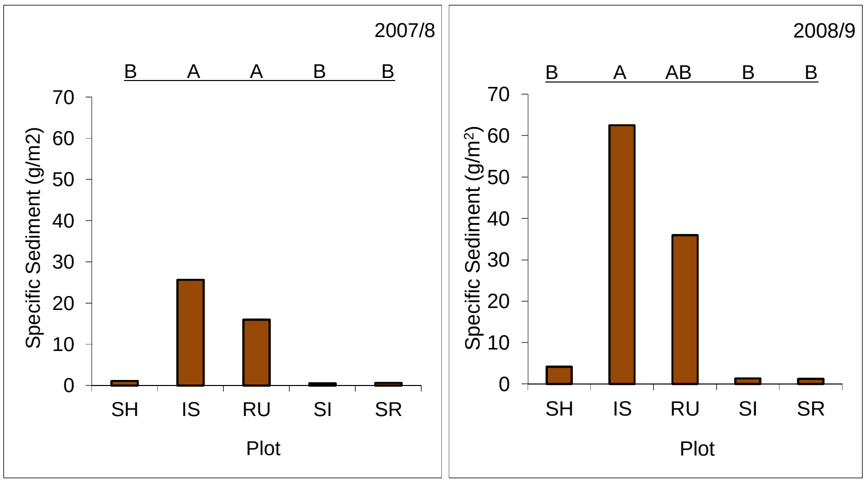


Fig. 6. Sediment yield in the various plots; winter seasons 2007/8 and 2008/9.

מעוצב:גופן: (ברירת מחדל) +גוף, 11 נק', מודגש, גופן עבור עברית ושפות אחרות: +גוף עברי, 11 נק', מודגש

SH=Shrub; IS=Intershrub; RU=Route; SI=Intershrub+Shrub; SR=Route+Shrub.

מעוצב:רגיל

Each value represents the mean of three replicates. For each year, means followed by different letters differ at *P* < 0.05.

עמוד 33: [1] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [2] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [3] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [4] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [5] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [6] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [7] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [8] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [9] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [10] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [11] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'

עמוד 33: [12] מעוצב moshiko 12/02/2015 09:52:00

גופן: 10 נק', גופן עבור עברית ושפות אחרות: 10 נק'