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Sustainability of Hillslopes in Semiarid Rangelands: Effects of Rock Fragments

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Abstract

Rock fragments (RFs) affect micro-environmental conditions in underlying and surrounding soil, and thereby stimulate abiotic and biotic processes that interact with the surrounding environment. Microenvironmental conditions are of great importance in arid and semiarid landscapes, where surfaces feature high percentages of RFs.

On south-facing hillslopes in the northern Negev region of Israel, soil was sampled from beneath small, medium, and large RFs – i.e., 4-6, 8-10, and 13-16 cm, respectively – that lay on the surface or were partially embedded in the soil. Control samples were taken from nearby bare soil.

Rock fragment characteristics affected various soil properties with differing intensities. Under large and medium RFs soil moisture contents were higher than under the small ones; and embedded RFs promoted higher moisture contents than those lying on top of the soil (designated as "on top"). Rock fragment position had the most significant effect on soil organic matter content, which was higher under on-top fragments than under embedded ones. The amplitude of soil temperature variation in all microenvironments followed that of air temperature. Soil temperature gradients underneath RFs of the various sizes, and most notably of those on top, and the differences among microenvironments depended on atmospheric conditions.

The RFs can be seen as fertile micro-islands, i.e., they concentrate natural resources and release them to the environment, thereby forming potential habitats for various fauna and flora. Soil quality is improved under RFs, which thereby compensate for the impaired quality of the exposed soil. The present paper presents a conceptual model of the contribution of RFs to hillslope sustainability in rangelands.

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Introduction

Rock fragment effect on the environment

Rock fragments (RFs) vary in size, shape, position, porosity and color [1-6] and bulk density [7], and accordingly there are variations in microenvironmental conditions, such as moisture content and temperature, in the underlying soil. These conditions, which influence abiotic and biotic processes that interact with the surrounding environment, are of great importance in semiarid and arid regions [8-11], whose landscapes are characterized by high percentages of RFs [12].

Various studies addressed the effects of RFs on: soil infiltration and percolation, and runoff generation [1,2,13]; spatio-temporal variations of soil water content [6,14]; and soil organic matter content and bulk density [3,13,15].

How RFs affect hydrological processes depends on their size, position, i.e., how they are integrated into the soil surface, and their percentage coverage: they may facilitate or hinder infiltration and, respectively, reduce or promote overland flow and soil erosion [16,17]. Lavee and Poesen [1] found that overland flow was positively related to RF size and coverage, and inversely related to separation between RFs. Partially embedded RFs (referred to below as "embedded") intensify surface sealing and crust formation in the contact zone between the rock fragment and the soil surface [18], thereby reducing infiltration in their surroundings. Surface-lying (referred to below as "on top") RFs: (i) protect the soil from raindrop-impact-driven compaction and splash [1,16,19,17]; (ii) prevent sealing of soil structural pores, thereby preventing mechanical crusting [18] and maintaining high soil porosity, because of biological activity and large numbers of wet/dry cycles , and thereby promoting infiltration and, consequently, diminishing overland flow generation and soil erosion compared with embedded RFs [17,19,20]. In contrast, when raindrops hit the bare soil surface directly they cause crusting of the topsoil and generation of overland flow [21].

Most notably, a positive correlation was found between RF cover percentage and soil moisture content [6,22,23,24]. However, under conditions of severe drought the opposite occurred: stony soils conserved less water than stone-free soils, though soils with large cobbles on the surface conserved the most water [3. The size of the fragments covering the soil has a strong influence on its water budget: soil water content under large single boulders was higher than in contiguous bare sandy soil; the difference in water content between the bare sand and the soil under blocks increased nearly eightfold as block size increased from 46 to 88 cm. This was attributed to effective insulation and reduction of evaporation by the larger boulders [5]. Valentin and Casenave [25] compared infiltration rates in soils covered with stones of a broad range of sizes – 2-20, 21-75, and 76-150 mm – in the Sahelian zone: they found that infiltration

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rates increased with increasing size of on-top gravels up to a median size of 29 mm, then decreased as fragment size increased further; unfortunately, no clear reasons for this were presented. Several authors [12,13,23,25] have commented on the ambivalent effects of clast layers on infiltration and runoff generation, and have concluded that this complex relationship depends on a number of factors in addition to fragment size. Regarding the effects of size and position, many studies [5,13,26,15,23,27] reached similar conclusions: the greater the increase in RF size – specifically of embedded RFs – the more of its area becomes shaded in the underlying soil, and therefore shielded from direct solar radiation. Large and medium-size embedded RFs maintained higher soil moisture contents than on-top small ones throughout the year, except for the end of summer, when the differences were found to be negligible [14].

Reported effects of RFs on soil temperature are ambivalent: [3] Danatalos et al. reported that stony soils were generally warmer during daytime and cooler at night than RF-free soils whereas, in contrast, Pérez [5] found that the soil temperature and amplitude of diurnal temperature variation of RF-covered soils were lower than those of bare sandy talus.

The color of surface rocks induces additional effects on soil moisture content, because lighter-colored RFs induce lower evaporation rates than darker ones [28,26] (). This is because the greater albedo of light-colored RFs causes them to heat up less quickly than dark ones, with consequently lower diurnal soil temperatures beneath them [29,26].

Studies of agricultural and natural areas in arid zones emphasized the beneficial effects of surficial 'gravel mulches', which can reduce soil water losses, influence overland flow generation, moderate soil temperatures, and increase plant productivity [13,30,15,18,3,5].

Rock fragment movement

The effects of livestock on the movement and spatial pattern of RFs have received little attention. In the northern Ethiopian highlands Nyssen et al. [31] found that transport of RFs caused by livestock traffic was an important geomorphic process on debris slopes. In a Mediterranean region in southwest Turkey, Govers and Poesen [32] found that sheep and goat traffic contributed to the downward movement of RFs on steep slopes; they noted that in intensively grazed areas with steep slopes, trampling could be an important factor in generation of stony colluvium on the foot-slopes. On the Greek island of Lesbos, Oostwoud Wijdenes et al. [33] found that trampling by sheep caused movement of RFs by as much as several meters; in some areas the exposure of soil resulting from loss of RF cover led to soil erosion and landscape deterioration. Sarah [34], working in the semiarid, north-western Judean Desert of Israel, found that the RF cover was greatest in the upslope proximity of shrubs, because of grazing activity. Considerable movement of RFs was found in the area of the present study site: in the Northern Negev of Israel, where RFs were distributed as clusters that occurred upslope of shrubs, or as scattered individuals on top of or embedded in the topsoil that occurred in the open spaces between shrubs. In this area the probabilities of an RF being moved were 86, 60, and 5%, for initial location on trampling routes, intershrub spaces, and next to shrubs, respectively [35].

The aims of the present study were to investigate the effects of RFs – of varied sizes and positions – on soil temperature, moisture, organic matter and calcium carbonate contents, and to assess the ecological benefits of RFs. The study hypotheses were that: (i) RFs improve soil quality; (ii) larger RFs result in greater soil moisture, calcium carbonate and organic matter contents; and (iii) on-top RFs promote higher soil organic matter and calcium carbonate contents than embedded ones.

Materials and Methods

Study area description

The research was conducted in the Goral Hills in the northern Negev region of Israel (31°20' N, 34°46' E) (Figure 1). This is a hilly, semiarid area, lying at 350–500 m above sea level, with mean annual precipitation of approximately 300 mm, most of which falls during October through May [36-38]. The winter is cold and rainy, with average daily temperature in January, the coldest month, of 10°C; the summer is hot and dry, with average daily temperature in August, the hottest month, of 25°C. Relative humidity ranges from 51% in May to 68% in January [36-39]. The lithology is chalk and limestone of the Eocene [38]. The soil – Leptosols – is shallow, generally not deeper than 20 cm in open spaces between shrubs and 40 cm under shrubs, 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 with a primary particle-size distribution of 30% clay, 40% silt, and 30% sand [10]. The dominant clay type is montmorillonite. 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% [10,40]. The mean gradient of the hillslopes is 15°. The study area, like many other semiarid areas of the Old World, has been grazed by flocks of sheep and goats since prehistoric times, i.e., for 5 000–8 000 years, therefore the vegetation mainly comprises grazing-tolerant species [41]. In the last 40 years the study area was subjected to moderate grazing pressure [34,42].

The landscape of sparse shrubland contains a patchy distribution of vegetation, biological crusts, exposed bedrock, and bare soil.

Figure 1: Map of Israel, showing the study region.

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The vegetation includes the following: *Sarcopoterium spinosum* (a moderately palatable dwarf shrub), *Coridothymus capitatus* (an unpalatable dwarf shrub), *Asphodelus ramosus* (an unpalatable geophyte), annual herbaceous vegetation, clumps of Poa bulbosa, biological crusts, rock fragments, exposed bedrock, and compacted bare soil of flock trampling routes. The research area comprises flock trampling routes, shrubs, and intershrub spaces, which cover 22, 17, and 61%, respectively, of the landscape [43].

Procedure

A survey of RF cover of all sizes was conducted on the backslopes of three randomly selected south-facing hill slopes, of gradient 13°. On each hillside, cover percentage, size and position of RFs was mapped with a (1 m × 1 m) frame with strings stretched across it to create a grid of 100 (0.1 m × 0.1 m) cells. Mapping was based on six random placements of the frame. Three size groups were designated – small, medium, and large, i.e., 4-6, 8-10, and 13-16 cm, respectively – for RFs positioned on the soil surface or partially embedded in the soil. The size of an RF was determined according to its longest dimension, and those that were smaller than 4 cm or larger than 16 cm were not studied: the former because the small underlying area was too small for soil sampling; the latter because of their rarity in the study area.

Soil sampling and measurements

Samples were taken from the soil beneath 120 randomly chosen RFs: 20 for each size and position. To maintain uniformity, soil from two depths – 0-2 and 5-10 cm – from an area of 12 cm2 beneath the center of the RF was sampled. In addition, control samples were taken from bare soil at the same depths, at 20 randomly selected points between RFs.

For each soil sample organic carbon, calcium carbonate and moisture contents were measured: by the wet combustion dichromate method [44], with a calcimeter [45,46] and gravimetrically, respectively.

Temperatures of the air at 1 m height and of the soil at the above two depths underneath the RFs and in bare soil, were measured. These measurements were taken once between the 1st and the 3rd of each month at 12:00–14:00; a digital Multi-Thermometer (Extech Instrument,) was used.

Data processing

Statistical analyses were applied with EXCEL and SAS software. The data were subjected to the non-parametric Duncan's multiple range test [47] at the $P < 0.05$ significance level, to determine significant differences among effects of RF size, RF position, and soil depth.

The coefficient of variation (CV) was used for comparing the degree of variation from data series of each property for the RF size, RF position, and soil depth. It is defined as the ratio of the standard deviation to the mean. The ratio is multiplied by 100 to express CV as a percent [48].

Results

Rock fragments – most (60%) of them smaller than 4 cm – occupied about 40% of the soil surface, and 40% of these were in the (4-16)-cm size range. About 50% of the studied RFs were small, and examination of their positions indicate that on-top and embedded RFs formed 61.2 and 38.8%, respectively, of their coverage (Table 1).

	Small	Medium	Large
Embedded	17.8	10.0	11.0
On top	32.4	16.9	11.9
Total for both positions	50.2	26.9	22.9
Embedded	On top		
38.8	61.2		

Table1: Rock fragment cover (%) in the study site.

Soil moisture content increased with depth in bare soil and also for each size and position of RF; mean values were lowest in the bare soil (Table 2). At both depths, soil moisture contents were significantly higher under the large and medium RFs than under the small ones. In general, embedded RFs promoted higher moisture contents than on-top ones. Coefficients of variation (CVs) were higher for bare soil than for that under RFs.

Depth (cm)	Cover type	N	Mean	Std.	CV (%)
			(%)		
0-2	BS	20	6.9 d	1.7	24.3
	ERS	20	10.2 c	1.8	17.6
	ERM	20	12.3 b	1.5	12.5
	ERL	20	13.8 a	1.7	12.2
5-10	BS	20	12.1 bc	1.9	15.6
	ERS	20	11.8 c	2.3	19.4
	ERM	20	13.3 b	1.5	11.1
	ERL	20	15.1 a	1.2	8.0
0-2	BS	20	6.9 c	1.7	24.3
	ORS	20	9.9 b	1.5	15.4
	ORM	20	11.3 ab	2.6	23.0
	ORL	20	11.8 a	2.1	18.0
5-10	BS	20	12.1 b	1.9	15.6
	ORS	20	11.3 b	1.7	15.4
	ORM	20	12.7 ab	1.6	12.9
	ORL	20	14.2 a	2.9	20.1

Table 2: Statistical parameters of soil moisture associated with the various microenvironments.

Note: For each position and for each depth, means within a column followed by different letters differ at $p = 0.05$.
BS = bare soil, ERS and ORM = embedded and on-top small rock fragment (RF), respectively; ERM and ORM = embedded and on-top medium RFs, respectively; ERL and ORM = embedded and on-top large RFs, respectively. CV = coefficient of variation. Std =Standard deviation.

Soil organic matter content decreased with depth in bare soil and also for each size and position of RF (Table 3); mean values were less in bare soil than underneath RFs of various sizes and positions. In general, on-top RFs, especially large ones, promoted higher organic matter contents than embedded ones. Coefficients of variation were moderate and similar for all microenvironments (Table 3).

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Depth (cm)	Cover type	Mean (g kg^{-1})	Std.	CV (%)
0-2	BS	18.4 a	4.7	25.49
	ERS	19.0 a	5.9	30.78
	ERM	23.0 a	6.6	28.43
	ERL	22.7 a	6.3	27.45
5-10	BS	17.2 b	2.2	12.78
	ERS	18.0 a	4.0	22.37
	ERM	21.5 a	6.4	29.81
	ERL	20.8 ab	4.5	21.69
0-2	BS	18.4 b	4.7	25.49
	ORS	22.7 ab	5.7	25.21
	ORM	24.2 a	6.3	25.87
	ORL	26.9 a	5.9	21.99
5-10	BS	17.2 b	2.2	12.78
	ORS	19.6 ab	4.8	24.45
	ORM	20.4 ab	5.9	29.18
	ORL	24.9 a	10.7	42.87

Table 3: Statistical parameters of soil organic matter associated with the various microenvironments.

For each position and for each depth, means within a column followed by different letters differ at $p = 0.05$.
BS = bare soil, ERS and ORM = embedded and on-top small rock fragments (RFs), ERM and ORM = embedded and on-top medium RFs; ERL and ORM = embedded and on-top large RFs, CV = coefficient of variation.

Mean calcium carbonate content was lower in the bare soil than beneath RFs. Small RFs, at both depths and positions, promoted the highest contents. The means for on-top and embedded RFs were similar. Coefficients of variation were low in all microenvironments (Table 4).

Discussion

Bare soil vs. rock fragments

Differences between bare soil and that beneath rock fragments, with regard to soil/moisture relations, might change during a rain event and afterwards, in accordance with the following stages. In the first stage – the beginning of the rain – the bare soil becomes wetter than that underneath RFs, because they shelter the soil. The second stage might occur as rain continues, when the water contents of bare and covered soil reach equilibrium . Soil beneath on-top RFs will reach this stage sooner than that beneath embedded RFs, because the former soil is more exposed than the latter to wetting by runoff, and has greater infiltration capacity [1,17-19,23,]. The third stage starts when the rain stops and soil drying starts, during which soil moisture content is controlled by shading, which reduces evaporative losses [23]: evaporation processes are most intense in the bare soil, less so beneath on-top RFs, and least beneath embedded RFs. Therefore, drying rates diminish as we progress from bare soil, via that beneath on-top RFs, to that under embedded RFs. In arid areas a fourth stage can be reached as a result of a continuing hot dry season, because soil hygroscopic moisture occupies all areas, both bare soil and that under RFs [14].

Depth (cm)	Cover type	Mean (g kg^{-1})	Std.	CV (%)
0-2	BS	279.7 a	16.1	5.8
	ERS	288.8 a	15.5	3.4
	ERM	276.9 a	27.7	10.0
	ERL	281.8 a	25.6	9.1
5-10	BS	273.2 b	30.8	11.3
	ERS	300.0 a	25.2	8.4
	ERM	283.5 ab	27.9	9.9
	ERL	284.8 ab	27.1	9.5
0-2	BS	279.7 c	16.1	5.8
	ORS	303.0 a	19.8	6.5
	ORM	294.2 ab	14.0	4.8
	ORL	282.3 bc	19.2	6.8
5-10	BS	273.2 b	30.8	11.3
	ORS	300.7 a	22.0	7.3
	ORM	295.1 ab	21.4	7.3
	ORL	286.2 ab	38.3	13.4

Table 4: Statistical parameters of calcium carbonate associated with the various microenvironments

For each position and for each depth, means within a column followed by different letters differ at $p = 0.05$.
BS = bare soil, ERS and ORM = embedded and on-top small rock fragments (RFs), ERM and ORM = embedded and on-top medium RFs, respectively; ERL and ORM = embedded and on-top large RFs, respectively; CV = coefficient of variation.

Field conditions in the present study represented the third stage, i.e., soil drying by evaporative processes that depend on the effective insulation and reduction of evaporation. Whereas the bare soil was exposed to wind and to solar radiation, that under RFs was sheltered and, therefore, the soil moisture content in the bare soil was lower than that beneath RFs of various sizes and positions. This is consistent with findings of other studies [5,6,22,23,49]. Organic matter and calcium carbonate contents were linked to the role of the microenvironment as source or sink: floating litter and dissolved calcium carbonate – mostly from the dust resource – are transported by runoff from the bare soil and are trapped in sinks associated with the RFs [8,9], which also are sinks for wind-borne organic materials [50]. Thus, organic matter and calcium carbonate contents were less in the bare soil than in that beneath RFs, so that pedohydrological properties of the latter were improved. These findings are in agreement with the first hypothesis presented in the Introduction: that "rock fragments improve soil quality".

The spatial variability of soil moisture in the upper soil layer was lowest under the embedded RFs, highest in the bare soil, and intermediate under the on-top RFs (Figure 3): the soil underlying the embedded RFs is the most protected from direct solar radiation, that beneath the on-top RFs less so, and the bare soil least protected. This is consistent with other findings [14,15,23,22,26].

Compared with spatial variability of soil moisture: that of soil organic matter was higher, with mutually similar levels in bare soil and beneath RFs; and that of calcium carbonate was lower, with mutually similar levels in bare soil and beneath RFs.

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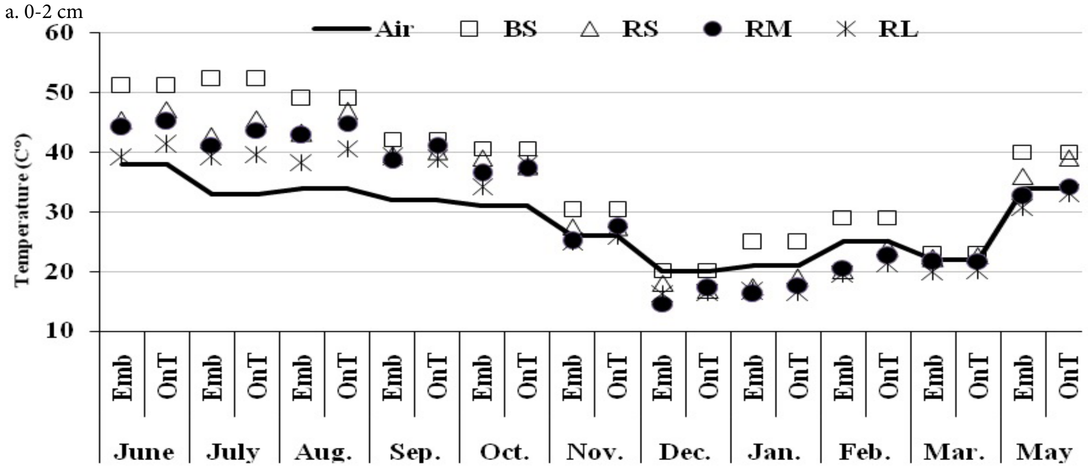
a. 0-2 cm



b. 5-10 cm

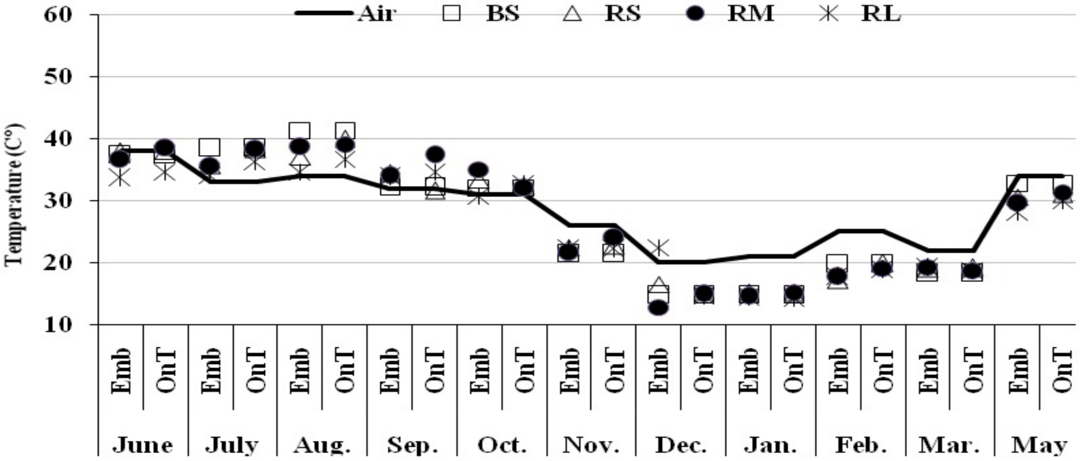


Figure 2: Air and soil temperature variations of the various microenvironments during one year (June 2006-May 2007). Each point represents a mean of 20 measurements.

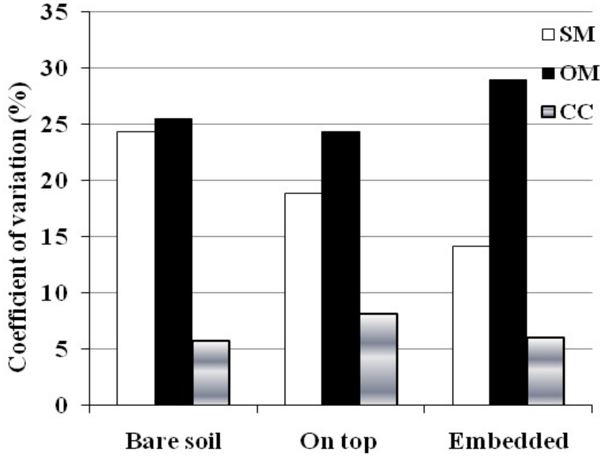


Figure 3: Coefficients of variation of soil moisture (SM), organic matter (OM) and calcium carbonate (CC) contents in the upper soil layer, in bare soil and RF positions.

Calcium carbonate responds slowly to environmental changes and therefore exhibits low spatial variability whereas, in contrast the soil organic matter is a quick-response property, which expresses the relations between sources of organic materials and the decomposing factors, i.e., soil biota [51]. These relations vary in space in each of the microenvironments, hence the moderate spatial variability.

The sizes and positions of RFs are expected to affect soil moisture content, which reflects the sensitivity of the various RFs to evaporative processes. Bigger RFs protect greater soil areas from direct solar radiation; closer contact between soil and RF more effectively prevents wind penetration beneath the rock fragment; and both tend to diminish evaporation [2,14,15,]. Therefore soil moisture increased with RF size, and was higher under embedded than under on-top RFs.

The effect of shielding the soil from direct solar radiation by RFs, combined with the moderating effect of soil moisture – the heat capacity of a soil is proportional to its moisture content [52] were seen in the differences in temperature of the soil beneath RFs of differing sizes and positions: in February at midday soil temperatures at both depths decreased with increasing RF size, especially beneath the on-top RFs, but were higher beneath on-top RFs than beneath embedded ones (Figure 4), which indicates that soil temperature is more affected by RF position than by RF size.

On-top RFs function as obstacles to transportation of litter and organic colloids by runoff and, therefore, are associated with biological activity and large numbers of wet/dry cycles [18,19], which increase soil aeration and aggregate stability, thereby encouraging soil penetration of organic colloids. Thus the highest organic matter contents occurred beneath the on-top RFs. In contrast, around the embedded RFs, litter might accumulate, but only for a short time,

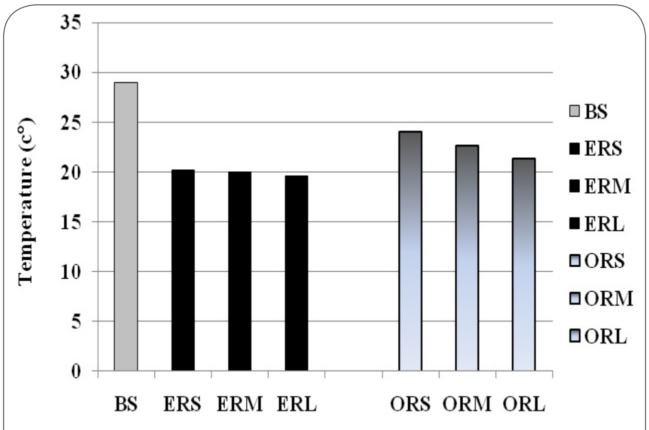


Figure 4: Soil temperatures in the upper soil layer in February.

so that decomposition of the litter is limited: it might be blown away by wind or washed away by runoff, i.e., embedded RFs intensify surface sealing and crust formation in the contact zone between the RF and the soil surface [18]. Thus there is a continuity of overland flow between the surfaces of the RF and the soil, so that litter might collect near embedded RFs but would be released to the environment by this continuous runoff. Therefore there were no differences among the various sizes of RFs, in organic matter content of their underlying soil. Calcium carbonate content was not affected by RF size or position. This might be attributed to slow chemical weathering processes of RFs in semiarid areas, and to shifting of RFs, which would prevent expression of continuous weathering in the carbonate content underneath them. These findings partly support the second and third hypotheses presented in the Introduction: only soil moisture content increased with RF size, and on-top RFs promoted higher and lower contents of soil organic matter and moisture, respectively, than embedded ones.

Annual temperature variations

Air and soil temperatures were measured around midday, therefore the following discussion relates only to variations in daily peak temperature. Relations between air and soil temperatures varied throughout the year (Figure 2): in the upper layer soil was notably warmer than the air by 10-20°C in the hot dry seasons of May through October, but in the cold wet months of December through March the differences were small, at 1-4°C. The air was warmer than the soil in the lower layer only in July and August; the opposite was found in the cold wet months. However, the upper layer showed more pronounced differences than the lower one, because of the direct impact of the atmosphere.

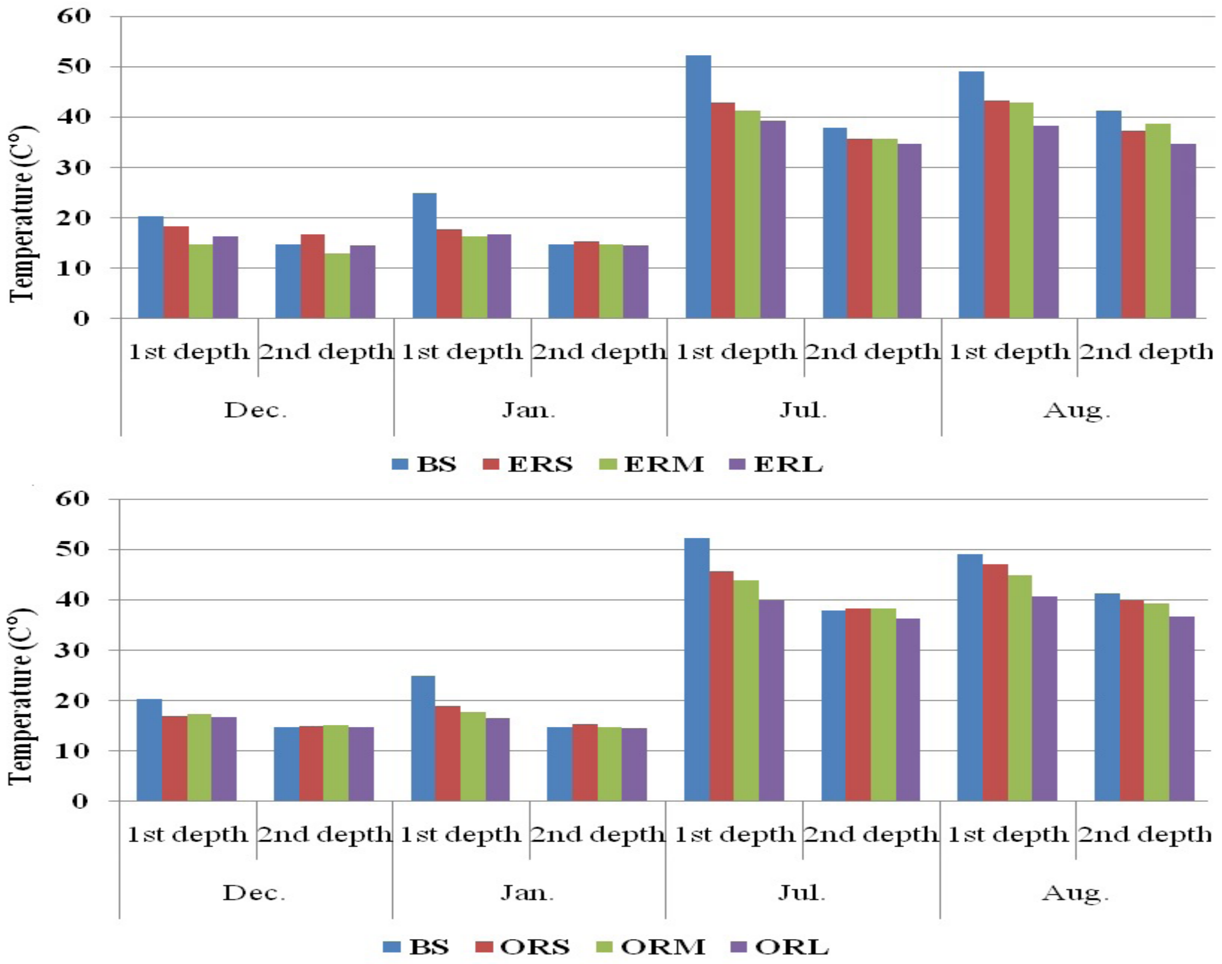


Figure 5: Soil temperature (C°) in the two soil depths of the bare soil and of the various RFs sizes of embedded (a) and on top (b) RFs, in selected winter and summer months.
BS = bare soil, ERS = embedded small RF, ERM = embedded medium RF, ERL = embedded large RF, ORS = on-top small RF, ORM = on-top medium RF, ORL= on-top large RF.

The annual amplitudes of soil temperature variation in the various microenvironments reflect the variations in air temperature, as modified by the surface cover soil type: in the hot dry seasons air temperature is higher and prevails for longer successions of months than in the cold wet ones; and the more the microenvironment is shaded and the greater the soil depth, the less effect the atmosphere has. Thus, the temperatures of the soil in all microenvironments was higher in the hot dry months, the soil temperature spatial gradients underneath the RFs of various sizes, and most notably those under the on-top RFs, were sharper, and the differences among microenvironments were higher than in the cold wet months (Figure 5). Similar trends were found by Pérez [5] for soil temperature and amplitude of diurnal variation beneath RFs and bare soil.

Conceptual Model

It is believed that the coexistence of RFs of different positions may have an important role in the long-term sustainability of the hillslopes. In Mediterranean areas sheep and goat traffic contributed to downward movement of RFs both on steep slopes [32,33] and moderate ones [35]. In intensively grazed areas with steep slopes, trampling could cause considerable downward movement of RFs, resulting in generation of stony colluvium at the foot of the slope and exposure of soil on its upper parts. Loss of RF cover leads to soil erosion and landscape deterioration. The present research area is characterized by moderate grazing intensity [42] which enables RF cover to persist on the hillslopes in spite of the movement of RFs.

A conceptual model of the effect of shifting of RFs by livestock on sustainability of a stony hillslope is suggested by the present findings. After movement of a rock fragment by an animal a fertile soil depression is exposed, which promotes favorable environmental conditions – with respect to water and organic matter – for seed germination and plant growth, and also might retain more rainfall than its surrounding area. These plants might be eaten by livestock and/or transformed into soil organic matter. At the same time, the relocated RF starts to improve the microenvironmental conditions in its new location, and functions as a sink for natural resources. In parallel, embedded RFs might become on-top ones because of soil erosion. Therefore, it can be considered that in the long term, with advancing time the whole hillslope would experience detachment and settling of RFs, i.e., over a long period each point on the hillslope is likely to function as a fertile area that serves as a preferable location for plant growth, and thereby increases the potential to produce soil organic matter and aggregation and to diminish soil erosion. By activating the movement of RFs, trampling livestock animals increase their own natural food supply, thereby promoting their "food security".

In arid areas, of all aspects, south-facing hillslopes present the driest environmental conditions [53] and have fewest shrub-promoted fertile islands. However, similarly to this function of shrubs, RFs serve as sinks for natural resources, and compensate to some extent for the lack of shrubs. Moreover, the quicker relocation of RFs than that of shrubs enables a more dynamic redistribution of the resources.

Conclusions

Presence of RFs can be very valuable in rangelands, particularly in dry areas and dry years; they conserve stored water and collect nutrients, thereby protecting large areas from desertification. Similarly to shrubs, RFs of the studied sizes, especially the medium and large ones, function as reservoirs of natural resources on the hillside; they can be regarded as fertile micro-islands, i.e., they concentrate natural resources and release them to the environment, and thus form potential habitats for varied fauna and flora.

Rock fragment position had the most significant effect on soil organic matter content, which was highest under "on-top" fragments.

In all microenvironments soil temperatures were higher in the hot dry months than in the cold wet months; soil temperature gradients were sharper underneath RFs of various sizes, and most notably under the on-top RFs, and the differences among microenvironments were higher.

Under the prevailing environmental conditions in the studied rangelands, i.e., semiarid climate and moderately intense grazing by 800 livestock animals on 800 ha, trampling by the livestock caused RFs to function in the long term as maintainers of a sustainable hillslope ecosystem. Such activity can be regarded as the action of an ecosystem engineer,

Competing Interests

The authors declare that they have no competing interests.

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