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ORIGINAL ARTICLE

The eco-geomorphological roles of rocky deep crevices for water supply on arid zone mountain slopes (case study: Mehriz–Yazd, Iran)

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Abstract Rocky slope landscapes are widely distributed on arid land mountains, where there are many restoration and forestation project sites. This study has surveyed the role of deep crevices and stone layers for supplying water to establish trees and shrubs on arid lands rocky slopes. The research was concentrated on the layers of Limestone, Granite and Andesite in central Iran. Thirty Transects, each 25 m long, were randomly laid out throughout the studied lithologic units. Correlation of vegetation cover percentage and abundance of trees were studied along with crack dimensions including width, depth, and length categorized into three classes; large, medium, and low sizes. Along those transects, the amount of EC, pH, organic materials, $CaSO_4$, $CaCO_3$, soil texture, N, P, K and soil moisture content in the cracks were also measured. The results showed significant differences ($p < 0/05$) among crack properties, vegetation cover and life forms in the study units. Also the vegetation cover and life forms have positive significant relationships with increase of crevice width as well as length and depth of each lithologic unit. The findings demonstrated that the inherent potential of limestone rocky slopes with deep layers is higher than other rocky units for restoration and afforestation in this arid region.

Keywords Rock layers · Arid land · Vegetation cover · Granite · Limestone · Andesite

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Introduction

Plant species often live in the cracks and rocky layers of arid lands (Porembski and Barthlott 2000). Rock cracks provide micro climate for arid lands vegetation and protect them against extreme environmental conditions, such as direct solar radiation (Lopez et al. 2009). Abundance of the endemic cactus, *Mammillaria fraileana*, is in relation with the fissure density, fracture depth of rocky layers, although these relationships show weak significant correlation (Lopez et al. 2009). Many rocky slope restoration projects carried out without proper scientific guidance may not to be very satisfactory which refer to lack information of plant growth on natural conditions of a slope (Shu et al. 2003; Wang et al. 2009). Surface crevices are the main water storage of plants in the arid rocky slopes ecosystems and are important contributors to soil quality (Powers and Ferrell 1996; Witty et al. 2003). The results of Porembski and Barthlott (2000) studies on inselbergs in arid zones indicated the role of granite rocks to support vascular plants against water limitation. In other hand, the role of succulent plants on breakdown igneous and degradation of volcanic rocks has been studied in desert area (Bashan et al. 2002, 2006). Other studies in humid and semi-arid climate areas have shown relation of heterogeneity and spatial patterns of plants with limestone dispersions and Karst development (Benites et al. 2007; Pérez-García and

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Meave 2004; Zhang et al. 2010; Lin et al. 2011; Zwieniecki and Newton 1996). Investigations of rocky slopes at Alborz and Zagros mountains in Iran also showed growth and regeneration of woody plants on varies slopes (Salarian et al. 2008; Ravanbakhsh and Marvie Mohajer 2010). Some researchers focused on changes of groundwater aquifer and assessed that as a water harvesting system (e.g., Pazand and Sarvestani 2013; Radfar et al. 2013; Nikiema et al. 2013; Wang et al. 2013; Alvarez et al. 2012; Yangui et al. 2011; Liu et al. 2011a, b; Fernandes et al. 2010) while there are rare studies on the rocky slopes of arid lands mountains. Studies at Mehriz region, central Iran, has showed that shrubs and rock-colonizing tree species (*Amygdalus scoparya, Ficus juhanica, Pistacia atlantica*) are grown in fissures of limestone rocks as primary colonizers. They produced small amount of soil by their own growth or

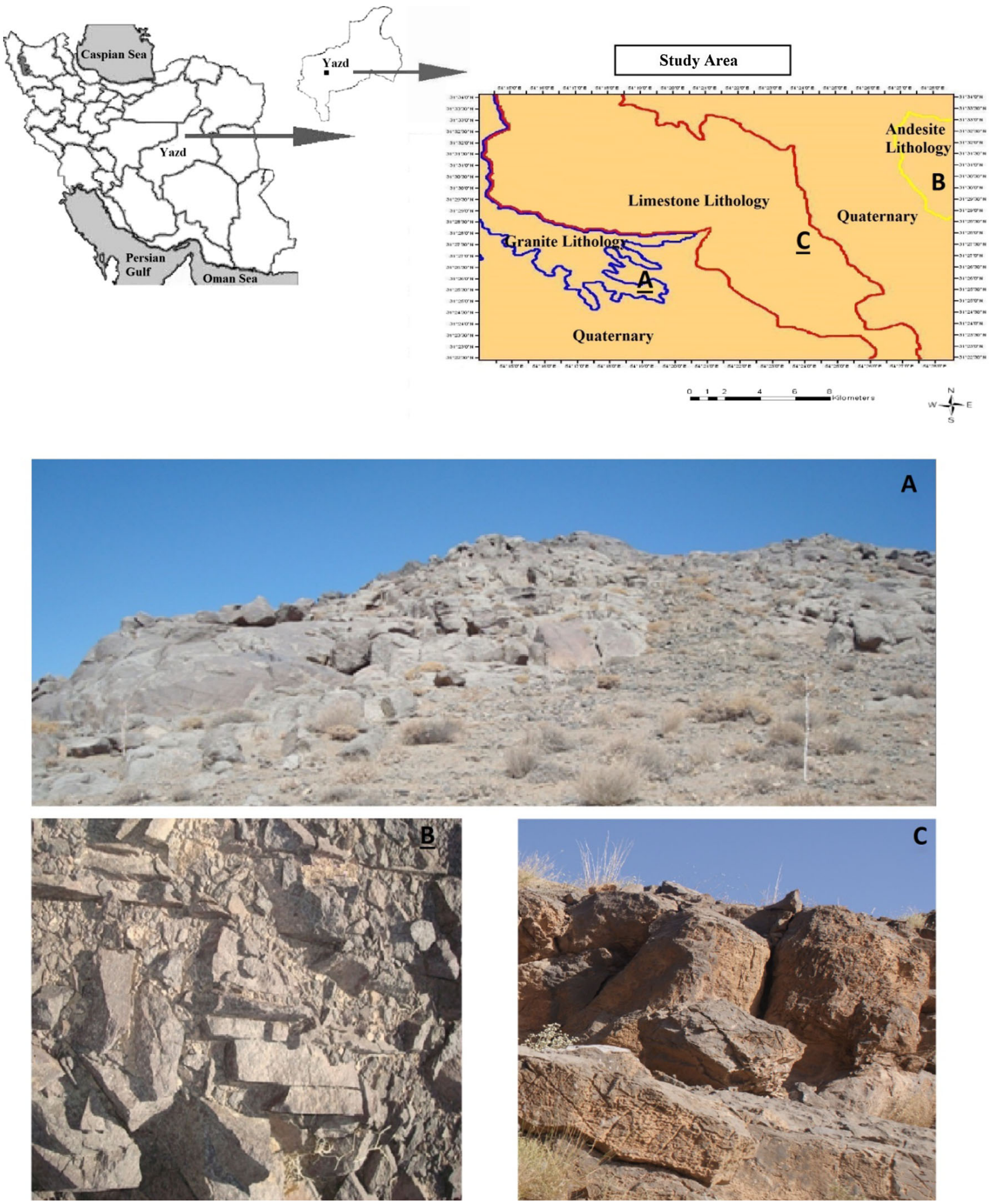

Fig. 1 Location of the study area; in this map has been shown the location of granitic (*blue line*, image **a**), andesitic (*yellow line*, image **b**), and limestone (*red line*, image **c**) geology units

sedimentation. Therefore, these species encourage soil and water accumulation in rocky slope crevices on bedrocks (Dashtakian and Baghestani 2002).

In the Mehriz region, as a case study of this work, rainfall from late fall to spring is insignificant; therefore, trees and shrubs are heavily independent to water storage in substrate layers. The main goals of this work are to clarify how different dimensions of cracks on lithologic units contribute soil quality in arid ecosystems, and what is role of limestone bedrocks growth of trees. It was hypothesized that different measured crevice properties might be in related to local variation of vegetation cover percentage (VC %) and number of trees within different geology units. A further assumption was that crevices in different lithologic habitats would show meaningful differences. Based on Whittaker (1972) and Whittaker and Woodwell (1972) studies, geomorphic heterogeneity considered one of the most important environmental characteristics influencing the numbers of plant species in a given area for some time. In addition, high correlations of VC and tree density with crevice properties showed to emphasizing VC (%) and number of trees in different lithologic units, such as igneous and sedimentary rocks (granite, andesite and limestone).

Materials and methods

Study area position

In this research, the rocky layers of three lithologic types (limestone, granite and andesite) were studied in the Mehriz region of Yazd province, located in central Iran (54°13′52″ to 54°32′19″E and 31°22′37″ to 31°34′53″N) (Fig. 1). Based on a modified De Martonne classification method, this area has cold-arid climate (Botzan et al. 1998), with a mean annual rainfall of 189 mm and a high inter-annual variability. The mean annual temperature is 12.2 °C. In the studied region, the hottest month is August and the coldest is February, with mean monthly maximum and minimum temperatures of 24.4 and 1.8 °C, respectively. In respect to geomorphology, the studied sites are located on mountain units. Rocky slopes are the most abundant landscape types seen in these mountains (Table 1).

Methodology

The methodology of this study is expressed in three parts: data collection, measurement, and analysis. In this research to measure vegetation cover percentage, intercept measurements have been calculated along a transect line with 25 m length. Soil properties was also assessed along the transect line where it overlapped with soil and other deposits.

Data collection

Based on Crépin and Johnson (1993), a stratified random sampling scheme was designed for analyzing the variability within and between sites (lithologic units). 30 transects, each 25 m long, were randomly laid out throughout the study area (Table 1). Along these transects the following were measured: vegetation cover percentage (VC) and large crack width (LCW), medium crack width (MCW), small crack width (SCW), large crack depth (LCD), medium crack depth (MCD), small crack depth (SCD), large crack length (LCL), medium crack length (MCL), small crack length (SCL) and numbers of trees. Crevice numbers possessing these properties were determined with respect to the classification shown in Table 2. Classification of crevice dimensions based on their width, depth and length,

Table 1 Characteristic parameters and indices of lithology for three rocky slopes of Mehriz Mountains, central Iran

Parameter	Site type		
	Limestone	Granite	Andesite
Weathering degree	Weakly weathered	Moderately weathered	Moderately weathered
Rock mass	Massive structure	Sub-massive structure	Sub-massive structure
Area (ha)	5,600	3,549	2,583
Plant type	*Amigdalus scoparia-Astragalus spp.*	*Astragalus spp.-Hertia angostifolia*	*Salsola sp.*
Tree species	Tree and shrub	Shrub	Shrub
Plant life form	*Amigdalus scoparia, Ficus jouhanic, Pistasia atlantica*	–	–
Slope aspect	North	North	North
Gradient (%)	15–100	15–100	5–100
Elevation (m)	1,800–2,400	2,200–2,450	1,600–2,250
Soil type	Typic xerorthents	Typic xerorthents	Typic xerorthents

Table 2 Classification of crevices according to width, depth and length (in cm)

Scale of crevices	Low	Medium	High
Width	0–4	4–10	>10
Depth	0–10	10–30	>30
Length	0–20	20–50	>50

Table 3 Comparison of the crevice properties and percentage of vegetation cover among three rocky slopes in Mehriz Mountain, central Iran

Parameter	Limestone rock	Granite rock	Andesite rock
LCW	7.06 ± 0.51[c]	4.16 ± 0.68[b]	0.00[a]
MCW	9.96 ± 0.59[c]	6.36 ± 0.83[b]	2.73 ± .55[a]
SCW	25.03 ± 2.25[a]	13.2 ± 1.83[a]	61.90 ± 10.41[b]
LCD	7.23 ± 0.69[c]	4.46 ± 0.73[b]	0.00[a]
MCD	9.66 ± 0.65[a]	4.53 ± 0.58[b]	7.26 ± .90[a]
SCD	25.16 ± 2.28[a]	14.60 ± 1.73[a]	57.36 ± 10.19[b]
LCL	11.40 ± 1.11[b]	5.33 ± 0.78[a]	6.40 ± 1.69[a]
MCL	10.90 ± 0.93[a]	8.9333 ± 1.00[a]	20.03 ± 4.47[b]
SCL	19.76 ± 1.86[a]	9.33 ± 1.77[a]	38.23 ± 8.30[b]
N	30	30	30

Mean ± SE calculated from the direct measurement. The number of samples was given

Where letters in superscript differ, data are significantly different ($p < 0.05$) by Tukey multiple range test

was by gathering experts' opinions and ultimately categorizing crack scales. The depths of the crevices were measured using a steel band. Positions of transects were randomly established in the landscape along vertical and horizontal gradients. Slope (%) was measured using clinometers. Aspects have been measured with respect to true north and were recorded as the azimuth (u) (McCune and Keon 2002).

The stochastic methodology for transect in this research means that based on the determined altitude, transect was done for each lithologic unit under random method. In other words, although the selection of transect location was random, the distribution was logical and all of lithologic units were transected.

According to the Table 2, for each fracture dimension, a range has been determined. The goal was a classification based on the values for the width, depth and length. The volume of cracks increases with increasing width, depth or length which provides more space to keep moisture and soil to grow vegetation cover.

Soil measurements

To quantify soil characteristics, soil samples of three crevice depths ranges (0–30, 10–30 and 30–50 cm) were

Table 4 Physical and chemical parameters of soils on the three lithology of Mehriz Mountain, central Iran

Parameter	Andesite lithology			Granite lithology			Limestone lithology		*N*
Depth (cm)	0–10	10–30	30–50	0–10	10–30	30–50	0–10	10–30	
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	20
Gravel (%)	23.20 ± 1.26[b]	21.30 ± 1.67[b]	19.80 ± 1.97[b]	41.40 ± 0.86[c]	38.95 ± 1.40[c]	36.55 ± 1.40[c]	12.57 ± 1.19[a]	10.75 ± 0.78[a]	20
pH	8.13 ± 0 03[b]	8.22 ± 0.06[b]	8.25 ± 0.05[b]	7.64 ± 0.08[a]	7.69 ± 0.09[a]	7.77 ± 0.08[a]	7.73 ± 0.07[a]	7.70 ± 0.08[a]	20
EC (ds/m)	0.11 ± 0.003	0.11 ± 0.004	0.14 ± 0.038	0.08 ± 0.002	0.08 ± 0.005	0.09 ± 0.001	0.14 ± 0.039	0.14 ± 0.011	20
$CaSO_4$, (%)	0	0	0	0	0	0	0		20
CaCO3 (%)	19.25 ± 0.80[b]	21.50 ± 0.69[b]	21.55 ± 0.62[b]	10.52 ± 0.44[a]	10.56 ± 0.44[a]	10.36 ± 0.41[a]	11.87 ± 0.40[a]	12.02 ± 0.40[a]	20
Organic matter (g/kg)	0.78 ± 0.01	0.76 ± 0.01	0.76 ± 0.01	0.88 ± 0.10	1.02 ± 0.10	0.98 ± 0.04	1.01 ± 0.07	0.93 ± 0.02	20
Moisture content (%)	0.78 ± 0.11[a]	8.07 ± 0.33[bc]	10.12 ± 0.28[d]	0.75 ± 0.08[a]	7.68 ± 0.33[b]	8.95 ± 0.23[c]	0.83 ± 0.12[a]	7.34 ± 0.29[b]	20
Total P (g/kg)	0.78 ± 0.02	0.75 ± 0.02	0.74 ± 0.02	0.77 ± 0.02	0.77 ± 0.01	0.76 ± 0.01	0.77 ± 0.02	.75 ± 0.01	20
Total N (g/kg)	0.44 ± 0.02	0.45 ± 0.02	0.42 ±0.03	0.46 ± 0.02	0.45 ± 0.03	0.45 ± 0.03	0.47 ± 0.02	0.44 ± 0.02	20
Total K (g/kg)	5.41 ± 0.15	5.27 ± 0.20	5.34 ± 0.19	5.86 ± 0.26	4.92 ± 0.29	5.34 ± 0.23	5.39 ± 0.24	5.47 ± 0.14	20

Mean ± SE calculated from the direct measurement. Numbers of samples are given

Where letters in superscript differ, data are significantly different ($p < 0.05$) by Tukey's multiple range test

Table 5 Spearman's correlation coefficient between vegetation cover and number of different crack properties in each geology unit and also combined

Parameter	Limestone				Granite		Andesite		All lithologies (limestone, granite, andesite)	
	VC (%)	*p*	Number of trees	*p*	VC (%)	*p*	VC (%)	*p*	VC (%)	*p*
LCW	0.64**	0.000	0.67**	0.000	0.48**	0.007	–	–	0.73**	0.000
MCW	0.46**	0.009	0.28	0.129	0.50**	0.004	0.09	0.624	0.68**	0.000
SCW	−0.18	0.331	0.01	0.955	−0.58**	0.001	0.20	0.278	0.01	0.874
LCD	0.67**	0.000	0.61**	0.000	0.52**	0.003	0.00	0.00	0.74**	0.000
MCD	0.52**	0.003	0.56**	0.001	0.51**	0.004	0.55**	0.002	0.52**	0.000
SCD	−0.14	0.439	−0.003	0.987	−0.51**	0.004	0.18	0.328	0.03	0.757
LCL	0.51**	0.004	0.50**	0.005	0.45*	0.011	0.47**	0.008	0.64**	0.000
MCL	0.26	0.158	0.37*	0.039	0.14	0.453	0.52**	0.003	0.28**	0.007
SCL	−0.16	0.372	−0.09	0.619	−0.14	0.441	−0.05	0.77	0.11	0.276
VC (%)	31.46 ± 2.97[b]	>0.05	0.80	0.000	10.12 ± 1.11[a]	>0.05	10.00	–	5.93 ± 0.74[a]	>0.05
N	30		30		30		30		90	

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

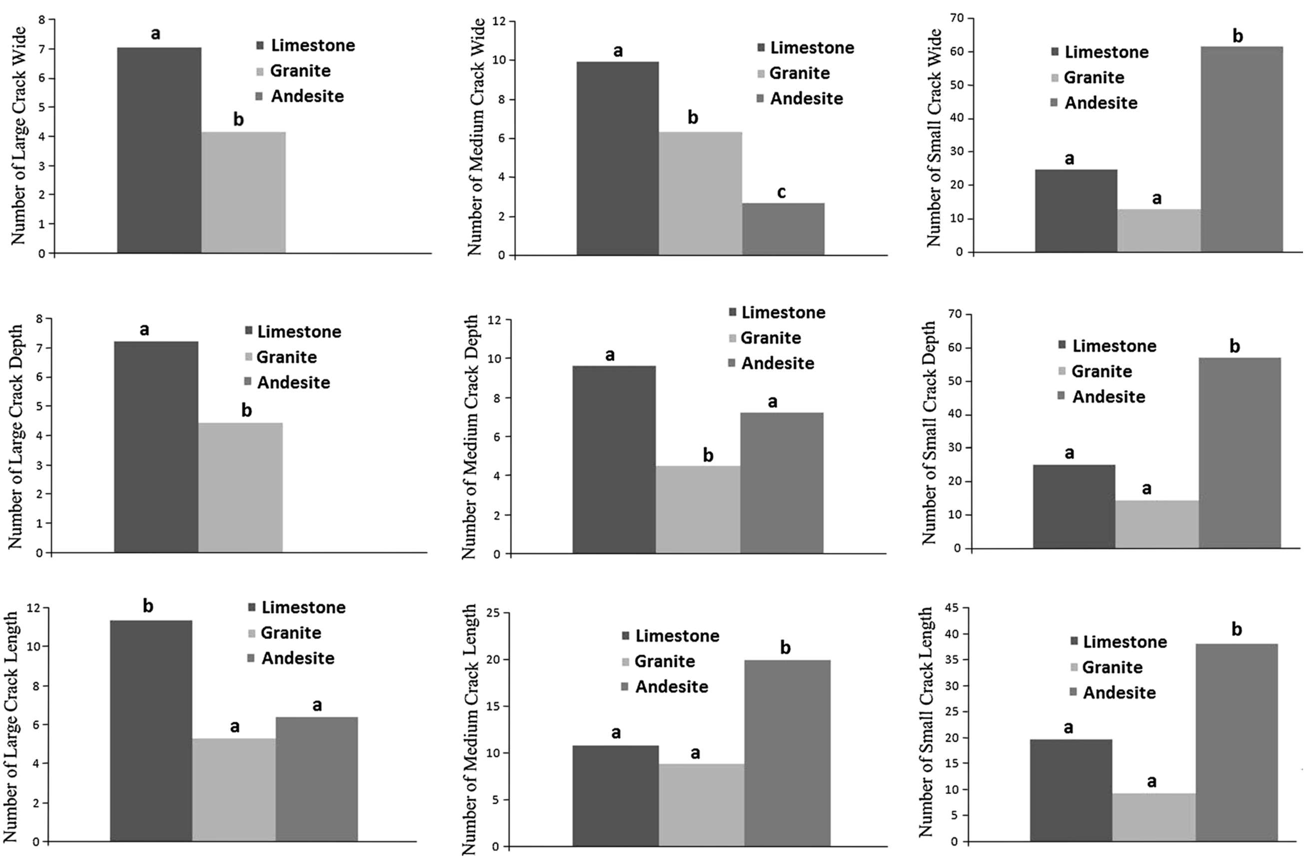

Fig. 2 Tukey mean separation for the number of crevice of the three different lithologic units

randomly taken on twenty crevices of each geology unit. After preparing the soil samples, they were analysed in the laboratory. Then the soil samples were passed through a 10-mesh (2 mm) screen to determine gravel content. In addition, for particles finer than 2 mm a physical test for determining clay, silt and sand amounts was applied. Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos 1962). Soil moisture contents were measured by the oven-dry method (dried at 105 °C to constant weight). Electrical conductivity (EC) was determined on a saturated soil paste. Calcium carbonate was determined by neutralization of HCl and titration of NaOH (Nelson 1982). Soil acidity (pH) was measured in distilled water by pH meter equipped with a glass electrode and calomel reference cell; total inorganic carbonate was assessed with the Colorimetric method by Spectrophotometer and the Shiebler calcimeter method (Allison and Moodie 1965). Also, total soil organic matter (SOM) was assessed with the Walkley–Black wet oxidation method (Allison 1965). Total nitrogen was determined by the Kjeldahl method (McGeehan and Naylor 1988), total potassium was estimated by flame photometry (Shi and Bao 1980) and total phosphate by the sodium carbonate (Na_2CO_3) and fusion—Molybdenum blue photometric method (Syers et al. 1967).

The amount of lime was calculated based on Total Neutralizing Value (TNV) through the volume method using the neutralizing reaction with HCL (Goh et al. 1993).

Data analysis

Statistical analysis of variance (ANOVA) was applied using SPSS (version 13). Tukey's multiple-range test was used for mean separation to determine significant differences ($p = 0.05$) in the number of different crevice properties and soil characteristics among the three lithologic units. A Spearman's Rank Correlation test was performed to analyze correlations between lithological properties, VC (%) and number of trees.

Results

The following, findings of the research are explained according to the properties of cracks, vegetation cover and lithologic units.

Rock crevices properties

The crevice parameter values of the three lithological types are shown in Tables 3 and 4. The cracks on the limestone with low and medium sizes in width and depth showed more significant differences compared with the same properties on the other lithologic units including andesite and granite. This difference was significant for cracks on the limestone compared with others for low length also. On the granitic rocky slopes, these parameters have higher values than those on the andesitic rocky slopes. Therefore, the values of LCW, MCW, LCD, MCD and LCL have directly significant relationships with vegetation cover, with higher crevice properties on the limestone and granitic rocky slopes, than on the andesitic rocky slope (Tables 3).

Soil properties

Analysis of soil properties showed that only pH, gravel, lime and moisture content were significantly different among sites (Table 4). In all lithologic units, positive relationships were revealed between depth and soil moisture content, while there was a significant difference between three depths of soil within rocky layers. Limestone contains highest amount of soil moisture content that is seen in 30–50 cm depth of layers. At this depth, there was a significant difference between limestone and other lithology units with moisture content. For all crevice depths among the lithologic units, soil properties including total nitrogen, total phosphorus, total potassium, electrical conductivity, soil texture, and organic material showed no significant differences.

Spearman's correlation coefficient between vegetation cover and crevice properties

After studying the crevice properties and soil characteristics on different lithologic units in relation to the vegetation cover of the rocky slopes and the life forms, we analyzed the relationships between these parameters by calculating the Spearman's correlation coefficient as shown in (Table 5). A significant difference was observed in vegetation cover (VC) in the studied units. Investigations of the geology units showed that the highest percentage was in

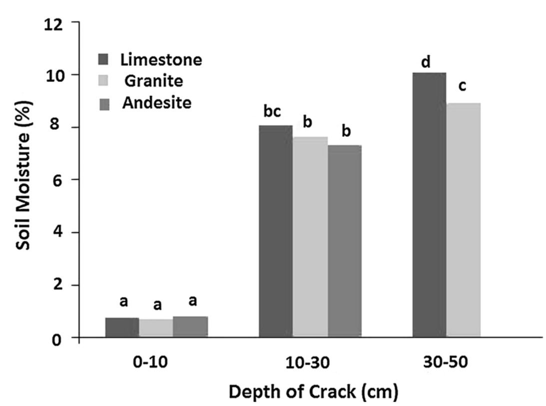

Fig. 3 Tukey mean separation for the soil moisture content of the crevices of three different lithologic units [Letters of *a*, *b*, *c*, *d*, and *bc* show significant or non-significant differences in probability level 5 % (95 % confidence)]. *bc* indicates moisture regime of depth 10–30 cm in limestone between moisture regimes *b* and *c*. For instance histograms with letter of *b* indicate that in each of lithology with each of depth have same moisture regimes

limestone (31.46 %) and the lowest vegetation density was in granite and andesite, with 10.12 and 5.93 %, respectively. In all lithologic units of the studied area, no significant positive correlation was seen among values of SCW, SCD and SCL. Also in each lithology unit involving limestone, granite and andesite, there was no significant positive correlation between the values of the mentioned properties and vegetation cover. There were significant relationships between medium width and depth cracks with vegetation cover in all lithologic units. In the limestone unit, statistically positive significant correlations were found between the vegetation density and low and medium cracks. Positive correlations were found between large and medium cracks in andesite, and vegetation cover. Also a direct correlation was found between values of low and medium dimension of cracks with vegetation cover in the granitic unit. In the limestone lithologic unit, the number of trees showed a positive correlation with the values of low and medium sizes in cracks including depth, length and width.

Discussion

Rock slopes have a number of characteristics which inhibit root development, such as highly impervious bedrock, limited soil volume, and lack of space (Nagy and Proctor 1997; Bashan et al. 2002, 2006). Soil accumulation on rocky slopes is a key factor enabling the establishment of vegetation cover in early succession stages, but due to the rainfall impact and severe water erosion, it is difficult to maintain soil protection on a rocky slope surface (Wang et al. 2009). Sometimes, the accumulation of soil in rocky cracks provides conditions to establish plant cover (Wiegleb and Felinks 2001; Wang et al. 2009). The mineralogical composition, texture and pore characteristics of

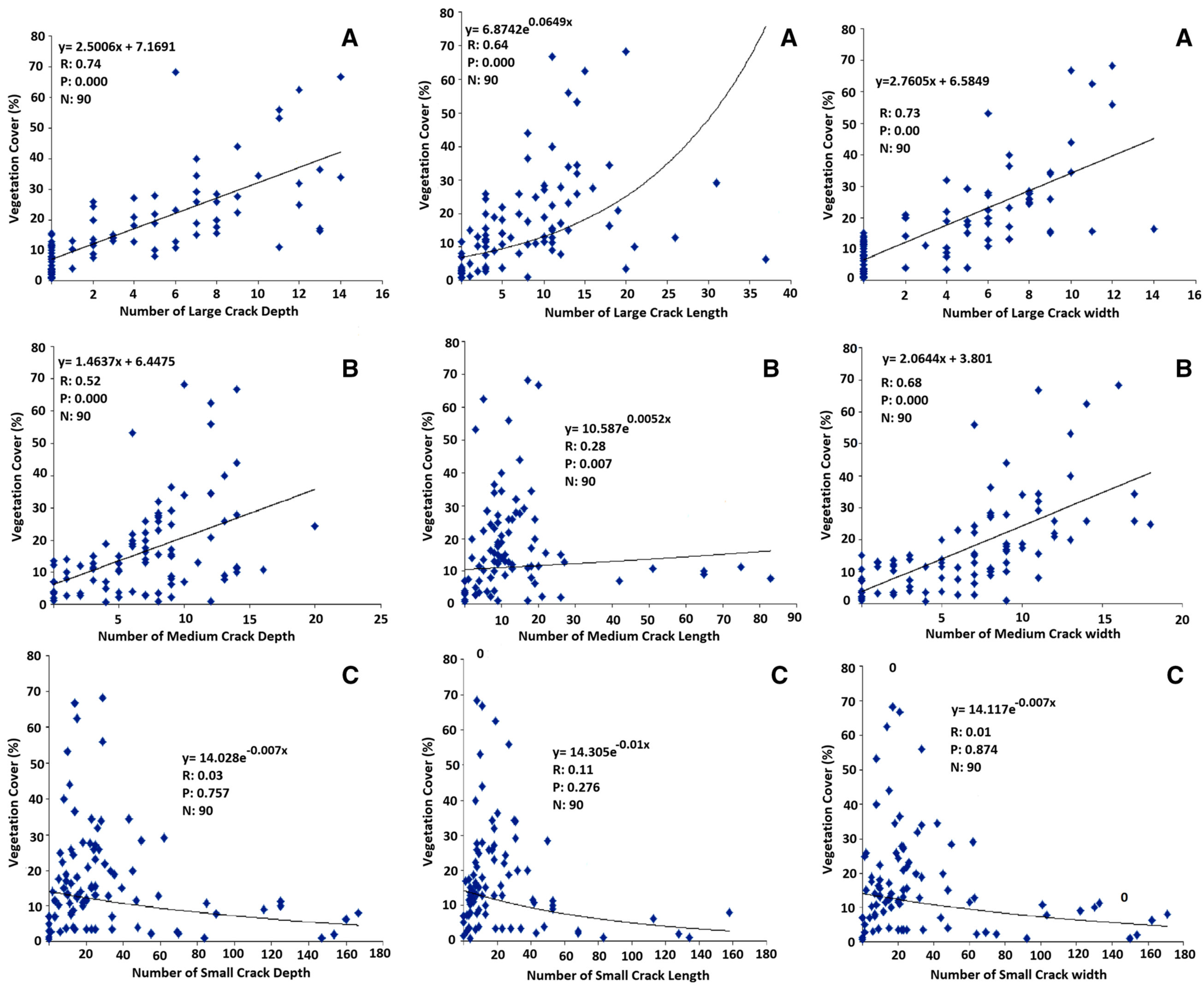

Fig. 4 The relationship between number of LCW (**a**), MCD (**b**), SCW (**c**), LCD (**d**), MCD (**e**), SCD (**f**), LCL (**g**), MCL (**h**), SCL (**i**) and VC of all three different lithology units

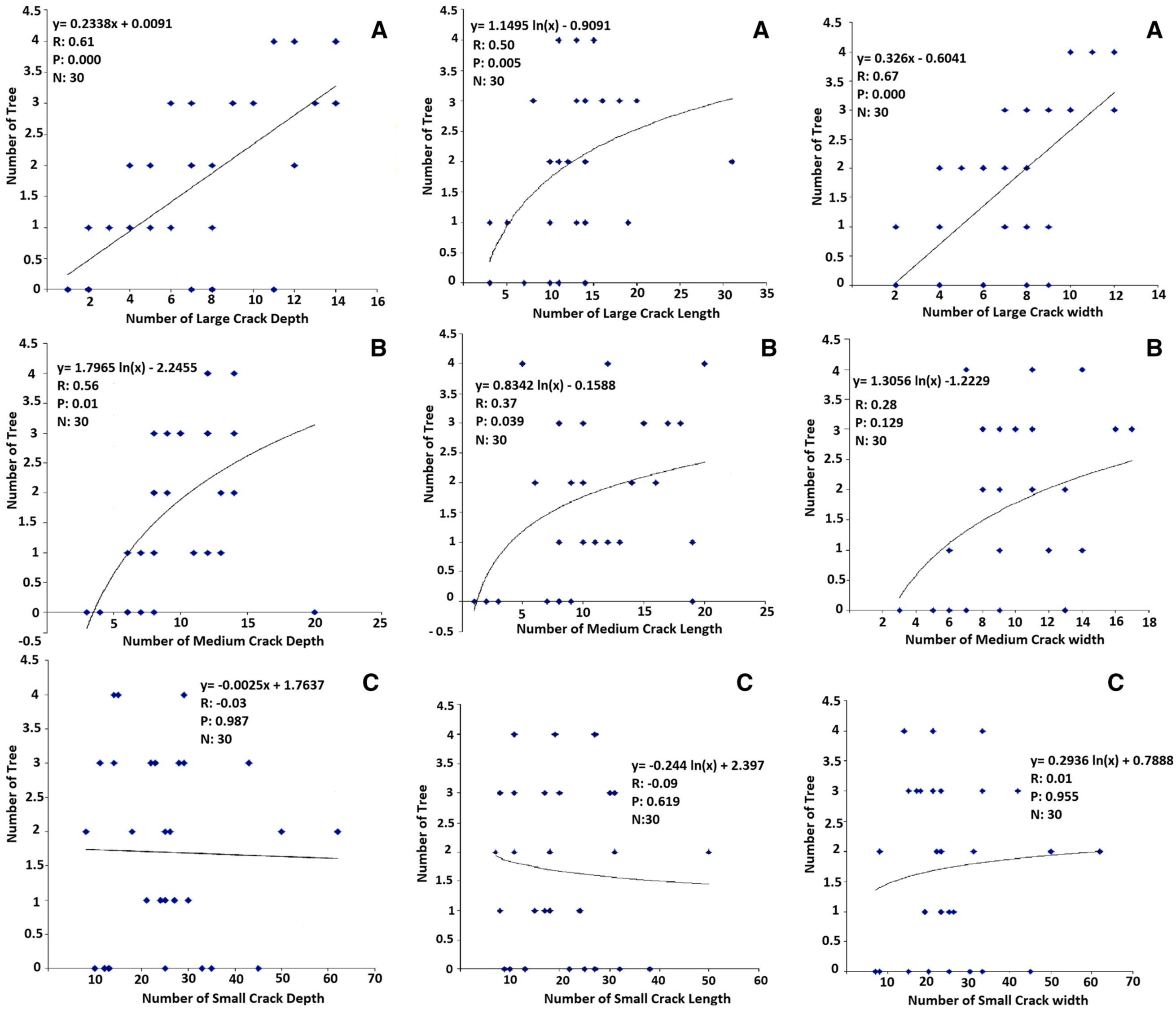

Fig. 5 The relationship between number of LCW (**a**), MCD (**b**), SCW (**c**), LCD (**d**), MCD (**e**), SCD (**f**), LCL (**g**), MCL (**h**), SCL (**i**), and number of trees of limestone lithology unit

different rocks are the main factors that control the intensity of features such as cracks (Hudec 1998). This research indicated that the numbers of crack properties significantly varied with lithology (Fig. 2). There were high numbers of cracks on the rocky slopes of limestone units. Deep fractures and cracks exist between layers of limestone formation (Fig. 2) and other sedimentary rocks. This finding confirmed the opinion of Jing (2003) about the relationship between cracks and geology formations. Igneous rocky geology units (for example granitic and andesitic) have less inherent porosity and the available moisture content is poor in these geology units (Tuğrul 2003).

Figure 3 shows that the moisture content at 30–50 cm depth in the limestone unit has are significantly higher than on the granitic and andesitic rocky slopes (Fig. 3). The layering structure could partially explain why there was a higher moisture content on the limestone rocky slope rather than on other lithology units. A low amount of available water is one of the most important limiting environmental conditions for plant inhabitation on the rocks (Martinez 1999; Nobel and Zutta 2007; Lopez et al. 2009; Alan 1997; Huang et al. 2005).

The reasons causing significant difference between diverse lithology units in relation to vegetation cover and life forms are as follows.

Figures 4 and 5 show how different crevice properties influence the vegetation cover in each geology unit (Figs. 4, 5). Wherever the soil is adequate on crevices and rocky depressions, there it is no doubt that the roots will be able to penetrate and anchor in the rock crevices (Li et al. 2007).

Fig. 6 Established shrub species on the small width and deep crevice of the andesitic rocks (**a**), vegetation associated with granite boulders and crevices of granitic rock (**c**), *Ficus juhanica* tree growing in a limestone crevice (**e**). *Ficus juhanica* tree growing in crevice located between two layers (*upper layer* and *lower layer*) on a limestone rocky slope (**e**), natural restoration of *Amygdalus scoparya* and *Pistacia atlantica* in a crevice on a limestone rocky slope (**d** and **b**, respectively). Schematic of limestone rocky slope layering (**g**). Surface crevice helped shrub species to establish on the limestone rock (**h**)

Field observations showed that plant roots were mostly concentrated in bedrock crevices. Environmental factors, such as soil nutrients and soil moisture, may lead to varied patterns of root distributions (Coutts 1987; Canadell et al. 1996). The roots could be more extended in wider crevices (Li et al. 2007). Plant roots creating anchors in crevices will cause significant deformation in the crevices, especially in the areas where the crevice width is smaller than the roots sizes on the bedrock surface. Root systems in the crevices had an overall flat shape instead of a circular one when being outside the crevices (Li et al. 2007).

It is known that roots tend to grow into the crevices under drought stress and whenever the moisture content in the crevices is suitable they concentrate at higher levels. This common phenomenon on the natural rocky slopes is showed in Fig. 7. Water conditions have driven the extension of roots into the crevices (Li et al. 2007). Eight dry months between April until November indicated that considerable water stress for plant species in the studied area is a common phenomenon. Therefore, due to the different water requirement of plants and the physical variations of the growth substrate (bedrock), which are essential

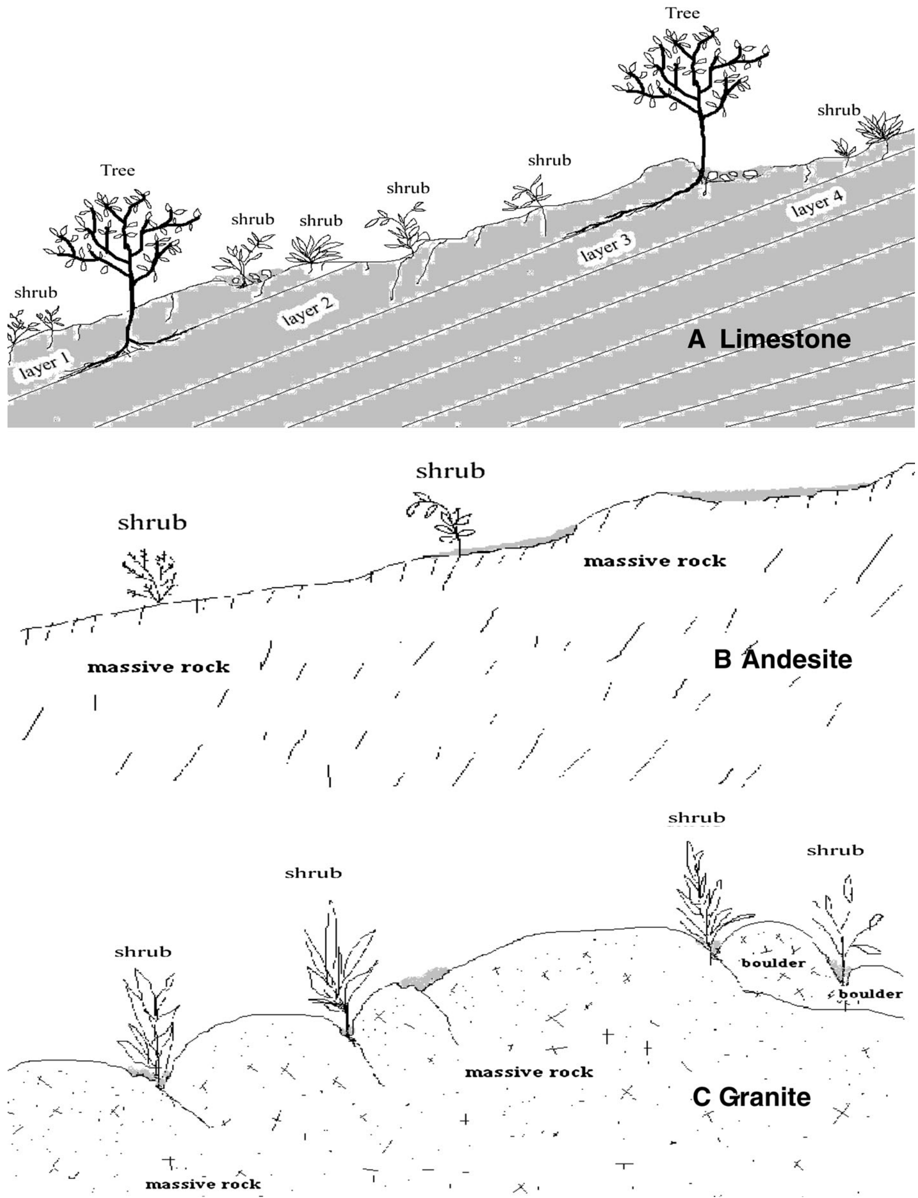

Fig. 7 Schematic of growth substrate for plant species on the three rocky slopes. **a** Limestone, **b** andesite and **c** granite

components of the plant water supply system and are important contributors to soil quality (Witty et al. 2003), the form of plant life will be diverse, especially in an arid region. *Amigdalus scoparya* is dominant tree species of limestone rocky slopes. Other tree species grown in this lithological unit are *Ficus juhanica* and *Pistacia atlantica*.

It is obvious that plant communities of rocky slopes that mainly contain tree species have relatively few desiccation-tolerant species (Porembski and Barthlott 2000). Therefore, under the same climate, these plant communities were only established on the lithologic units with more available water in the surface crevices. The ability to take up stored water in the surfaces of crevices on the bedrock during the pronounced dry season is likely the key feature allowing plant species to thrive under dry conditions in the rocky slopes of the study area (Querejeta et al. 2006). The limestone lithological unit had the largest amounts of crevice parameters and vegetation covers, while only on this unit were tree species established. Tree species almost exclusively developed over limestone lithology rocky slopes. Plant life form of developed vegetation cover on the granitic and andesitic rocky slopes was only shrub species (Fig. 7). The main role of bedrock involves supporting tree transpiration during dry periods in ecosystems with shallow soils (e.g. Zwieniecki and Newton 1996; Hubbert et al. 2001; Rose et al. 2003). Furthermore, subsurface soil-filled cavities within the limestone bedrock can hold large volumes of water which can better prevent evaporation compared with water stored in superficial soil (Querejeta et al. 2007).Water stress was one of the most important limitative factors to grow species on rocky slope (Wang et al. 2009).

Plant species needing low water requirement such as shrubs are mostly established in small and medium size crevices, but those having a high water requirement, such as trees, are mostly established in large crevices (Figs. 6, 7a). Therefore, it was clarified why seedlings of plant species (especially tree species) in the study site have frequently extended their roots into the surface crevices (1–4 m) of different lithology units (Jackson et al. 1999; Stratton et al. 2000; Sternberg et al. 2002), but only low numbers of those survived during the pronounced dry seasons.

Due to the direct relationship between soil moisture content and increase of crevice depth as well as the significant difference between the number of crevice parameters in limestone, granitic and andesitic lithology units, the results explain why there were significant differences between the three different lithological units in respect to vegetation cover and life forms (Lopez et al. 2009). In summary, this is probably the first or one of the first surveys to establish the way in which different lithological units affect the inherent potential for plant establishment on arid lands rocky slopes.

Conclusion

Lithological deserts and rocky landscape occur over wide parts of arid areas in Iran. Establishment of vegetation cover in these severe landscapes occurs in places where competition for water is low. Crevices and cracks on the rocks are locations for supplying water to establish trees and vegetation cover in these areas. The objective of this study was to provide an overview about the important role of surface crevice properties of different lithologic units in influencing vegetation cover and plant life forms due to plant water supply and soil accumulation. Investigations of this research indicated that limestone units because of their greater ability to keep water in their cracks are more preferential sites for trees and shrubs. Also there is a significant correlation between the width size of cracks with life forms as well as for length and depth sizes. Igneous rocky geology units (for example granitic and andesitic) have less inherent porosity and the available moisture content is poor in these geology units. Results indicated that limestone unit with more than fractures and cracks compared granite and andesite units, are more suitable locations to establish vegetations. The survey results can be utilized for forest restoration projects in arid land mountains.

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References

Alan C (1997) Plant species coexistence in cliff habitats. J Biogeogr 24:483–494

Allison LE (1965) Organic carbon: Walkley-Black method. In: Agronomy Monographs 9, Part 2. Methods of Analysis, American Society of Agronomy, Madison. Wisconsin, pp 1367–1378

Allison LE, Moodie CD (1965) Carbonate: Volumetric Calcimeter Method. In: Agronomy Monographs 9, Part 2. Methods of Analysis, American Society of Agronomy. Madison, Wisconsin, pp 1389–1392

Alvarez MD, Trovatto MM, Hernandez MA, Gonzalez N (2012) Groundwater flow model, recharge estimation and sustainability in an arid region of Patagonia, Argentina. Environ Earth Sci 66:2097–2108

Bashan Y, Li CY, Lebsky VK, Moreno M, de-Bashan LE (2002) Primary colonization of volcanic rocks by plants in arid Baja California, Mexico. Plant Biol 4:392–402

Bashan Y, Vierheilig H, Salazar BG, de-Bashan LE (2006) Primary colonization and breakdown of igneous rocks by endemic, succulent elephant trees (Pachycormus discolor) of the deserts in Baja California, Mexico. Naturwissenschaften 93:344–347

Benites VM, Schaefer CEGR, Simas FNB (2007) Soils associated with rock outcrops in the Brazilian mountain ranges Mantiqueira and Espinhaço. Revista Brasil Bot 30(4):569–577

Botzan TM, Marino MA, Necula AI (1998) Modified de Martonne aridity index: Application to the Napa Basin, California. J Environ Sci 19:55–70

Bouyoucos GJ (1962) Hydrometer method improved for making particle size analyses of soils. Agron J 54:464–465

Canadell JF, Dyrness CT (1973) Natural vegetation of Oregon and Washington. General technical report PNWS-8.417. USDA Forest Service, USA

Canadell J, Jackson RB, Ehleringer JR, Mooney HA, Sala OE, Schulze ED (1996) Maximum rooting depth of vegetation types at the global scale. Oecologia 108:583–595

Crépin J, Johnson RL (1993) Soil sampling for environmental assessment. In: Carter MR (ed) Soil sampling and methods of analysis. Lewis Publishers, Florida, pp 5–18

Coutts MP (1987) Developmental process in tree root systems. Can J For Res 17:761–767

Dashtakian K, Baghestani N (2002) Plant species type of Yazd, 1st edn. Tehran, Research Institute of Forests and Rangelands, Iran

Fernandes PG, Carreira PM, Bahir M, Al Arifi N, El Alfy M, Al Zaharani E (2010) Mass balance simulation and principal components analysis applied to groundwater resources: Essaouira basin (Morocco). Environ Earth Sci 59:1475–1484

Goh TB, Arnaud RJ, Mermut AR (1993) Aggregate stability to water. In: Cartner MR (ed) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, pp 177–180

Huang YL, Chen LD, Fu BJ, Zhang LP, Wang YL (2005) Evapotranspiration and soil moisture balance for vegetative restoration in a gully catchment on the Loess Plateau, China. Pedosphere 15:509–517

Hubbert KR, Beyers JL, Graham RC (2001) Roles of weathered bedrock and soil in seasonal water relations of *Pinus jeffreyi* and Arctostaphylos patula. Can J For Res 31:1947–1957

Hudec P (1998) Rock properties and physical processes of rapid weathering and deterioration. In: Moore DP, Hungr O (eds)

Proceedings of 8th International Congress of IAEG, vol 1. Balkema, Rotterdam, pp 335–341
Jackson PC, Meinzer FC, Bustamante M, Goldstein G, Franco A, Rundel PW, Caldas L, Igler E, Causin F (1999) Partitioning of soil water among tree species in a Brazilian Cerrado ecosystem. Tree Physiol 19:717–724
Jing L (2003) A reviews of techniques, advances and outstanding issues in numerical modeling for rock mechanics and rock engineering. Int J Rock Mech Min Sci 40:283–353
Li SC, Sun HL, Yang ZR, Xiong WL, Cui BS (2007) Anchorage of Vitex negundo L. on rocky slopes under different weathering degrees. Ecol Eng 3:27–33
Lin YC, Chang LW, Wang HH, Sun IF (2011) Point patterns of tree distribution determined by habitat heterogeneity and dispersal limitation. Oecologia 165:175–184
Liu CC, Liu YG, Guo K, Li GQ, Zheng YR, Yu LF, Yang R (2011a) Comparative ecophysiological responses to drought of two shrub and four tree species from karst habitats of southwestern China. Trees 25:537–549
Liu XH, He BL, Li ZX, Zhang JL, Wang L, Wang Z (2011b) Influence of land terracing on agricultural and ecological environment in the loess plateau regions of China. Environ Earth Sci 62:797–807
Lopez BR, Bashan Y, Bacilio M, Agu GDC (2009) Rock-colonizing plants: abundance of the endemic cactus Mammillaria fraileana related to rock type in the southern Sonoran Desert. Plant Ecol 201:575–588
Martinez CE (1999) Saxicolous and riparian vegetation of a piedmont in central-western Argentina. J Arid Environ 42:305–317
McCune B, Keon D (2002) Equations for potential annual direct incident radiation and heat load. J Veg Sci 13:603–606
McGeehan SL, Naylor DV (1988) Automated instrumental analysis of carbon and nitrogen in plant and. soil samples. Commun Soil Sci Plant Anal 19:493
Nagy L, Proctor J (1997) Soil Mg and Ni as causal factors o plant occurrence and distribution at the Meikle Kilrannoch ultramafic site in Scotland. New Phytol 135:561–566
Nelson RE (1982) Carbonate and gypsum. Part 2: Chemical and Microbiological Properties. In: Page AL, Miller RH, Keeny DR (eds) Methods of soil analysis. American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, pp 180–197
Nikiema J, Glasser W, Krieg R, Schirmer M (2013) Trace elements and their correlations in hand-dug wells in a laterite environment in a semi-arid region: case study of Tikar, Northern Burkina Faso. Environ Earth Sci 69:2393–2414
Nobel PS, Zutta BR (2007) Rock associations, root, depth, and temperature tolerances for the ''rock live-forever'' Dudleya saxosa, at three elevations in the north western Sonoran Desert. J Arid Environ 69:15–28
Pazand K, Sarvestani JF (2013) Hydrogeochemical investigation in an arid region of Iran (Tabas, Central Iran). Environ Earth Sci 70:281–293
Pérez-García EA, Meave JA (2004) Heterogeneity of xerophytic vegetation of limestone outcrops in a tropical deciduous forest region in southern México. Plant Ecol 175:147–163
Porembski S, Barthlott W (2000) Granitic and gneissic outcrops (inselbergs) as centers of diversity for desiccation-tolerant vascular plants. Plant Ecol 151:19–28
Powers RF, Ferrell GT (1996) Moisture, nutrient, and insect constraints on plantation growth: the ''Garden of Eden'' study. N Z J For Sci 26:126–144
Querejeta JI, Estrada-Medina H, Allen MF, Agüero GDC, Jiménez-Osornio JJ, Ruenes R (2006) Utilization of bedrock water by Brosimum alicastrum trees growing on shallow soil atop limestone in a dry tropical climate. Plant Soil 201:575–588
Querejeta JI, Estrada-Medina H, Allen MF, Jiménez-Osornio JJ (2007) Water source partitioning among trees growing on shallow karst soils in a seasonally dry tropical climate. Oecologia 152:26–36
Radfar M, Van Camp M, Walraevens K (2013) Drought impacts on long-term hydrodynamic behavior of groundwater in the tertiary-quaternary aquifer system of Shahrekord Plain, Iran. Environ Earth Sci 70:927–942
Ravanbakhsh H, Marvie Mohajer MR (2010) Natural regeneration of woody species in woodlands of southern slopes of Elborz mountains (case study: Latian watershed). Iran J For 2(2)
Salarian A, Mataji A, Iranmanesh Y (2008) Investigation on site demand of Almond *(Amygdalus scoparia* Spach.*)* in Zagros Forests (case study: Karebas site of Chaharmahal and Bakhtiari province). Iran J For Pop Res 16(4)
Rose KL, Graham RC, Parker DR (2003) Water source utilization by *Pinus jeffreyi* and Actostaphylos patula on thin soils over bedrock. Oecologia 134:46–54
Shi RH, Bao SD (1980) Soil agriculture chemistry analysis [M]. China Agriculture Press, Beijing, pp 191–197 (in Chinese)
Shu WS, Lan CY, Wang MH (2003) Early natural vegetation and soil seed banks in an abandoned quarry. Acta Ecol Sin 23:303–305
Sternberg LDL, Moreira MZ, Nepstad DC (2002) Uptake of water by lateral roots of small trees in an Amazonian Tropical Forest. Plant Soil 238:151–158
Stratton LC, Goldstein G, Meinzer FC (2000) Temporal and spatial partitioning of water resources among eight woody species in a Hawaiian dry forest. Oecologia 124:309–317
Syers JK, Williams JDH, Campbell AS, Walker TW (1967) The significance of apatite inclusions in soil phosphorous studies. Soil Sci Soc Am Proc 31:752–756
Tuğrul A (2003) The effect of weathering on pore geometry and compressive strength of selected rock types from Turkey. Eng Geol 75:215–227
Wang ZQ, Wu LH, Liu TT (2009) Revegetation of steep rocky slopes: planting climbing vegetation species in artificially drilled holes. Ecol Eng 35:1079–1084
Wang L, Mu Y, Zhang QF, Zhang XC (2013) Groundwater use by plants in a semi-arid coal-mining area at the Mu Us Desert frontier. Environ Earth Sci 69:1015–1024
Whittaker RH (1972) Evolution and measurement of species diversity. Taxon 21:213–251
Whittaker RH, Woodwell GM (1972) Evolution of natural communities. In: Wiens JA (ed) Ecosystem structure and function. Proceedings of the 31st Annual Biology
Wiegleb G, Felinks B (2001) Primary succession in postmining landscapes of lower Lusatia-change or necessity. Ecol Eng 17:127–199
Witty JH, Graham RC, Hubbert KR, Doolittle JA, Jonathan AW (2003) Contributions of water supply from the weathered bedrock zone to forest soil quality. Geoderma 114:389–400
Yangui H, Zouari K, Trabelsi R, Rozanski K (2011) Recharge mode and mineralization of groundwater in a semi-arid region: Sidi Bouzid plain (central Tunisia). Environ Earth Sci 63:969–979
Zhang ZH, Hu G, Zhu JD, Luo DH, Jian N (2010) Spatial patterns and interspecific associations of dominant tree species in two old-growth karst forests, SW China. Ecol Res 25:1151–1160
Zwieniecki MA, Newton M (1996) Seasonal pattern of water depletion from soil-rock profiles in a Mediterranean climate in southwestern Oregon. Can J For Res 26(8):1346–1352