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The effect of *Sarcopoterium spinosum* on soil and vegetation characteristics

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ABSTRACT

This study addressed the effect of the dwarf shrub *Sarcopoterium spinosum* on soil properties, soil moisture and vegetation characteristics (plant density and richness) in a semi-arid ecosystem. Vegetation characteristics and soil sample data were obtained from three areas: 1) beneath the *S. spinosum* patch, 2) between the patches and 3) from the open area. The results showed that the area beneath *S. spinosum* had significantly higher soil moisture content, organic matter, available ammonium, nitrate, and phosphorus compared to the areas between shrubs and open areas. The results also showed that the total plant density and richness decreased significantly beneath the shrub canopy compared to the areas between shrubs and open areas. Certain plant species are found only beneath the shrub canopy. Our results indicated that *S. spinosum* creates habitat heterogeneity by modifying the area beneath its canopy and influencing the community structure. Interactions and the mechanisms of interactions between *S. spinosum* and other annual plants play an important role in determining community structure and affecting the distribution of plant species beneath and around the shrub canopy. Thus, understanding such interactions and understanding their mechanisms are important issues that should be considered for rangeland management and conservation.

1. Introduction

In arid and semi-arid lands, the presence of shrubs and the interactions among the species create spatial heterogeneity that affects the distribution and performance of annual plants (Facelli and Temby, 2002). Annual plants are often closely associated with shrubs, and the degree of association largely depends on the balance of negative and positive effects between these contrasting plant life forms (Holzapfel et al., 2006). Shrubs may have important effects on annual plants growing outside the canopy (Caballero et al., 2008; Dickie et al., 2005; Facelli and Temby, 2002).

The effect of shrubs on plant heterogeneity may result from a combination of biotic and abiotic factors, including soil moisture, light penetration, temperature, seed availability, nutrient availability and water evaporation (Armas and Pugnaire, 2005; Casermeiro et al., 2004; Fu et al., 2003, 2004; Giladi et al., 2007; Pariente, 2002; Segoli et al., 2008; Segoli et al., in press; Seifan et al., 2010; Vinton and Burke, 1995). The establishment of such conditions under the shrubs enhances soil water retention and could increase water availability around the shrubs (Fu et al., 2003, 2004; Pariente, 2002).

For more than a century, rangeland in the West Bank has suffered from land degradation due to environmental conditions and human activities. For example, the cumulative effects of overgrazing in dry lands have caused soil erosion and runoff and consequently reduced vegetation cover and productivity. As a result of these factors, a number of unpalatable plant species dominate the area (Ali-shtayeh and Salahat, 2010; Mohammed, 2005; Salama and Aljoaba, 2008). In Mediterranean arid and semi-arid areas, *Sarcopoterium spinosum* is considered an indicator of rangeland degradation (Ackermann et al., 2004). It is an unpalatable dwarf shrub, 30–60 cm in height, with branches ending in dichotomous, leafless thorns (Litav and Orshan, 1971). It has a high rate of seed production and establishes itself rapidly and vigorously after disturbance to its canopy (Henkin and Seligman, 2002; Segoli et al., 2008).

In a study aimed at understanding community-level interactions among coexisting species, Holzapfel et al. (2006) found that the above-ground productivity, richness, seedling density, and seed bank density of annual plant communities as well as the fecundity of annual plant populations were generally higher at the edge of shrub stands than in the area between shrubs in arid and semi-arid areas. In addition, Mohammed (2005) stated that *S. spinosum* had an important role in protecting many plants by allowing them to hide inside the canopies of this shrub, especially under semi-arid overgrazing conditions.

Vegetation controls soil erosion via its canopy, roots, and litter components (Gyssels et al., 2005). In addition to the vegetation cover type and percentage, land use and soil conditions have a direct influence on rainfall runoff and soil erosion (Al-seekh and Mohammad, 2009; Andreu et al., 1995; Bochet et al., 1998; Casermeiro et al., 2004). Mohammad and Adam (2010) concluded that *S. spinosum* significantly decreased the amount of runoff and soil erosion and increased soil organic matter.

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Understanding the small-scale heterogeneity created by shrubs is an important issue for rangeland improvement and management in arid and semi-arid lands. Shrublands dominated by *S. spinosum* cover extensive areas in eastern Mediterranean ecosystems along the Mediterranean semi-arid climatic gradient (Evenari et al., 1986; Litav and Orshan, 1971). It follows that understanding the spatial development of this species is of great importance. Therefore, the aim of this study is to investigate the effect of *S. spinosum* on soil and plant characteristics in semi-arid Mediterranean rangeland.

2. Materials and methods

2.1. Study site

The study was conducted at BaniNoem during 2009. The site is located on the eastern slopes of the West Bank–Palestinian territory, 15 km east of Hebron City. The geographical position of the site is 35.108° east and 31.409° north. The topography is mountainous, with elevations ranging from 596 to 704 m above sea level. The climate of the site is classified as semi-arid. The average precipitation is approximately 250–300 mm (MOA, 2009), primarily in the form of short, high-intensity rainstorms. The site is characterized by long dry summers. The average temperature is 25 °C in the summer and 13 °C in the winter. The soil bedrock is calcareous (limestone or hard chalk) with shallow soil. According to Awadallah and Owaiwi (2005) the soil association in this site belongs to Brown Rendzinas and Pale Rendzinas. The area was used for many years as rangeland, but grazing has been excluded by fencing since 1995. According to previous studies in the area, the dominant plant species in natural vegetation are *Torilis tenella*, *Poa bulbosa*, *S. spinosum*, *Crithopsis delileana*, and *Helianthemum salicifolium* (Mohammad, 2008; Mohammed, 2005; Salama and Aljoaba, 2008).

2.2. Measurements and data collection

2.2.1. Plant density

Plant density was evaluated in April 2009 during the peak of primary production (Mohammad, 2008). Twenty 0.25 m∗0.25 m (0.0625 m^2) quadrats were randomly allocated as follows:

1- beneath *S. spinosum* canopy cover
2- between the *S. spinosum* shrubs (40–50 cm from the canopy)
3- in an open natural vegetation area (without *S. spinosum*). An area of approximately 2 donums without *S. spinosum* was located in the same study area.

Richness was calculated as the average number of species recorded in a 0.0625 m^2 quadrats, regardless the number of individuals of each species.

Plants were identified according to Al-Eisawi (1998), Zohary (1966), Burnie (1995), and Fragman et al. (1999). The number of species and the number of individuals of each species were recorded for each quadrat.

2.2.2. Soil properties

Soil chemical and physical properties were measured once in February 2009. Three replicate soil samples at a depth of 0–10 cm were randomly collected from each location. The bulk soil samples were air-dried, crushed with a mortar and pestle and sieved to remove coarse (>2 mm) fragments. The soil particle size distribution was determined with the pipette method (Bouwer, 1986a, 1986b). Soil pH was determined with an electrode pH meter for a saturated soil paste (1:2.5) prepared with distilled water.

Electrical conductivity (EC) was also measured in a saturated paste (1:2.5) (FAO, 1980; Skoog and West, 1976). Organic matter (OM) was determined as an organic carbon ratio in the sample with the Walkey and Black method (Nelson and Sommers, 1982). Extractable bases were determined following displacement with 1 M NH_4OAc (Thomas, 1982). The Olsen and Sommers (1982) method was used to determine extractable phosphorus with a molybdate reaction for colorimetric detection.

Four soil samples from 15 cm soil layers were collected at the end of the rainy season (April 1) from each location. Stones and plant residue were removed from the samples. The samples were then weighed and dried at 105 °C to a constant weight. The volumetric soil moisture percentage was computed on a dry-weight basis.

2.2.3. Statistical analysis

A one-way ANOVA was used to compare soil properties and plant density among the locations. A Fisher's LSD (least significant difference) test at $P \leq 0.05$ was used with Sigmastat® software to evaluate the differences between means.

3. Results

3.1. Soil properties

S. spinosum affected most tested soil properties (Table 1). *S. spinosum* significantly increased ($p<0.05$) soil EC beneath the canopy cover compared to the area between the *S. spinosum* shrubs and areas without *S. spinosum*. In addition, the soil beneath *S. spinosum* had significantly higher OM%, available nitrogen NH_4^+, NO_3^-, and phosphorus compared to the areas between and without *S. spinosum* shrubs (Table 1). However, the soil texture was similar among all locations.

No significant differences in soil pH and $CaCO_3$ were found among the locations.

The soil beneath *S. spinosum* shrubs had a significantly ($P<0.05$) higher moisture content than the other locations. The values of soil moisture content at the other locations were similar to each other (Fig. 1).

3.2. Vegetation

Plant density was significantly lower beneath the *S. spinosum* shrubs (99.2 plants/m^2) than in the area between the shrubs (493.6 plants/m^2) or the open area (540 plants/m^2) (Fig. 2). Similarly, plant richness was significantly reduced beneath *S. spinosum* (3.10 species per 0.0625 m^2) compared with the area between the shrubs (7.70 species per 0.0625 m^2) or the open area (8.55 species per 0.0625 m^2) (Fig. 3). The densities of the total grasses and forbs were higher in the open area and between the shrubs than beneath the shrubs (Fig. 4).

Table 1
Soil properties beneath *S. spinosum*, between *S. spinosum*, and in area without *S. spinosum*.

Treatments	Soil texture				O.M. %	EC (dsm^{-1})	pH (1:2.5)	NH_4^+ (ppm)	NO_3^- (ppm)	P (ppm)	$CaCO_3$ (%)
	Sand (%)	Silt (%)	Clay (%)	Texture class							
Beneath shrubs	48.0	13.2	48.0	Clay loam	4.4 a	0.35 a	6.9 a	3.2 a	5.9 a	3.9 a	24 a
Between shrubs	47.1	13.5	47.1	Clay loam	3.2 b	0.22 b	7.0 a	1.9 b	3.8 b	2.7 b	22 a
Without shrubs	47.1	14.6	47.1	Clay loam	2.9 b	0.23 b	7.1 a	2.0 b	2.5 b	2.6 b	23 a

Means followed by the same letter in the same column are not significantly different according to Fisher LSD test at ($P \leq 0.05$).

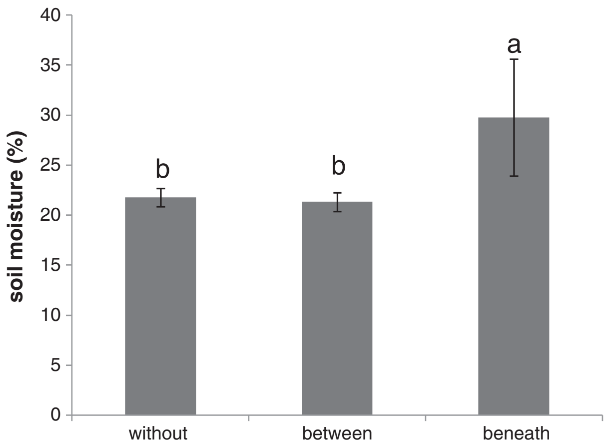

Fig. 1. Soil moisture content under shrub canopy (beneath), between the shrubs (between) and without the shrubs.

S. spinosum had direct effects on both the number and density of co-occurring plant species (Table 2). In all, 42 different plant species were found in the open area, 34 between the shrubs and 23 beneath the shrub canopy. Certain species showed higher densities beneath the shrubs: *Evax contracta* (5.6 plants.m^{-2}), *T. tenella* (25.6 plants.m^{-2}), *Avena sterilis* (5.6 plants.m^{-2}), *Bromus fasciculatus* (8.8 plants.m^{-2}), and *P. bulbosa* (27.2 plants.m^{-2}). In addition, certain plant species appeared only beneath *S. spinosum* (Table 2).

4. Discussion

4.1. Soil properties

Our results showed that *S. spinosum* in semi-arid conditions had positive effects on the soil organic matter and nutrients beneath its canopy. This result is in agreement with other studies (Boeken and Orenstain, 2001; Xie and Steinberger, 2001). The improved microclimate beneath the *S. spinosum* may be due to litter accumulation and the control of soil erosion and rainfall runoff (Segoli et al., 2008). These factors create a suitable environment for decomposer microorganisms.

Plant litter serves as a resource for decomposer organisms (Boeken and Orenstain, 2001) and a nutrient source for plants (Boeken and Orenstain, 2001; Facelli and Temby, 2002) as well as enhancing the availability of soil resources such as water (Fu et al., 2004; Mohammad and Adam, 2010; Segoli et al., in press). In addition, Rezaei and Gilkes (2005) found significantly higher soil P, NO_3^- and NH_4^+ concentrations beneath the shrubs compared to other areas. Moreover, these elements are beneath and close to the shrubs and are thus protected from water erosion as well as from drifting caused by wind (Mohammad and Adam, 2010; Pariente, 2002).

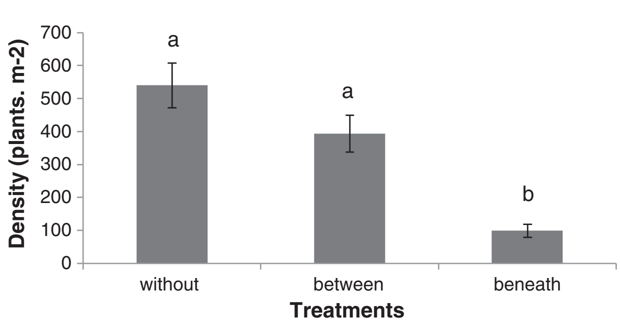

Fig. 2. Plant density (individuals/m^2) under shrub canopy (beneath), between the shrubs (between) and without the shrubs.

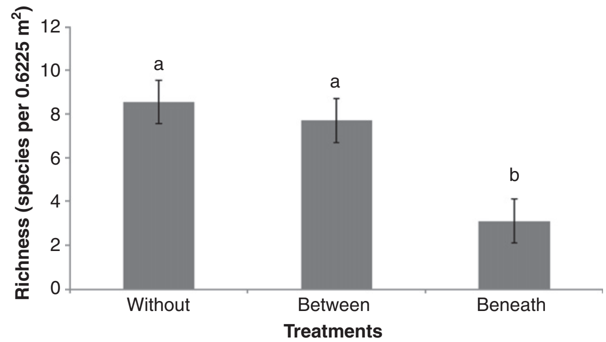

Fig. 3. Plant richness (species/0.0625 m^2) under shrub canopy (beneath), between the shrubs (between) and without the shrubs.

The soil beneath *S. spinosum* had a significantly higher soil moisture content than the soil in the other areas. These results are in agreement with previous studies conducted in arid and semi-arid environments (Casermeiro et al., 2004; Fu et al., 2003, 2004; Pariente, 2002; Segoli et al., 2012; Xie and Steinberger, 2001). The presence of shrubs creates shade that reduces light penetration and evaporation, and this process positively affects soil moisture (Flores and Jurado, 2003; Fu et al., 2003, 2004; Segoli et al., 2012; Turner et al., 1966). In addition, Pariente (2002) and Segoli et al. (2008) indicated that *S. spinosum* shrubs increased the infiltration rate and decreased water runoff and sedimentation.

The degree of association between the shrubs and herbaceous plants largely depends on the balance of negative and positive effects between these contracting plant life forms and can range from interference to facilitation (Holzapfel et al., 2006).

Our results indicated that the plant densities did not differ significantly between the areas between the shrubs and the open areas, while it was significantly decreased beneath the *S. spinosum* shrubs. In a study at similar environmental condition, Segoli et al. (2012) reported that the effects of *S. spinosum* on herbaceous vegetation are spatially heterogeneous and extended to 10 cm beyond the canopy. Reisman-Berman and Henkin (2007) found that the difference between facilitation and interference depended on the density of the canopy cover and that facilitation occurred at intermediate levels of canopy cover. Other studies showed that shrub roots have a facilitative effect on annual plant species and that this positive effect depended on water availability, root system structure and the distance from the canopy (Callaway and Walker, 1997; Facelli and Temby, 2002; Holmgren et al., 1997). However, *S. spinosum* could be

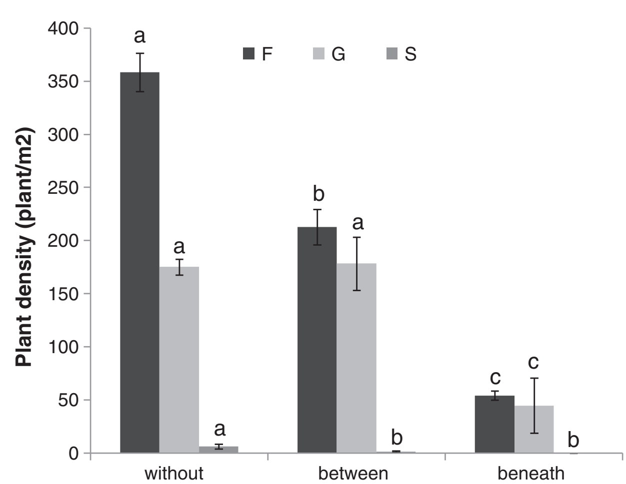

Fig. 4. Species density (individuals/m^2) under shrub canopy (beneath), between the shrubs (between) and without the shrubs. (F: forbs, G: grasses, S: shrubs).

the main cause of the absence of certain plant species beneath the canopy cover or between the shrubs. It has been predicted that facilitation among plant species is stronger in stressful sites, whereas interference predominates in less stressful environments (Bertness and Callaway, 1994; Callaway and Walker, 1997).

5. Conclusion

Under semi-arid conditions, plant density and richness are lower under the canopy of *S. spinosum*. Improving the availability of resources (organic matter, nutrients, and soil moisture) and protection from herbivores might be the primary reason for the presence of certain plant species under the canopies of *S. spinosum* shrubs. Therefore, the role of *S. spinosum* in shaping the rangeland vegetation under semi-arid conditions should be considered in rangeland management and in conserving natural vegetation. Retaining patches of *S. spinosum* might increase the heterogeneity of the rangeland vegetation. In addition, more research is required to fully understand the complex interference and facilitation processes between the shrubs and their understory vegetation under arid and semi-arid conditions.

Table 2
Plant density (plant/m^2) beneath the shrub canopy, between shrubs and in open area (without *S. spinosum*).

Scientific name	Beneath shrubs	Between shrubs	Without shrubs
Alcea acaulis	0	0	0.8
Allium erdelli	3.2	10.4	4
Amaranthus sp.	0	0	0.8
Anagallis arvensis	0	2.4	2.4
Anemone coronaria	0	0	1.6
Anthemis palestina	0.8	22.4	43.2
Astomaea seselifolium	0	0	3.2
Astragalus cruciatus	0	0	0.8
Atractylis cancellata	0	29.6	4
Biscutella didyma	2.4	5.6	28
Carlina hispanica	0	0	1.6
Centaurea iberica	0.8	0	2.4
Cichorium endivia	0	0	1.6
Coronilla scorpioides	0	0	0.8
Crepis aspera	0	10.4	3.2
Erodium acaule	2.4	16.8	6.4
Eryngium creticum	0	0.8	0
Euphorbia hierosolymitana	0	0.8	0.8
Evax contracta	5.6	67.2	42.4
Helianthemum salicifolium	0.8	20	5.6
Hippocrepis unisiliquosa	0	1.6	1.6
Lathyrus cicera	0.8	0.8	0.8
Lomelosia palaestina	0.8	0.8	4.8
Medicago orbiclaris	1.6	6.4	0.8
Melilotus sp.	4	12	20
Notobasis syriaca	0	1.6	2.4
Onobrychis caput-galli	2.4	0.8	9.6
Plantago afra	0	0	3.2
Rhagadiolus stellatus	0	1.6	8
Scorpiurus muricatus	0	0.8	0
Sinapis arvensis	1.6	4	4
Torilis tenella	25.6	61.6	74.4
Trifolium campestre	0.8	0	16.8
Trifolium stellatum	0.8	35.2	58.4
Total forbs	54.4	313.6	358.4
Aegilops geniculate	0	3.2	0
Avena sterilis	5.6	5.6	23.2
Brachypodium distachyon	1	16	2.4
Bromus fasciculatus	7.3	46.4	77.6
Bromus tectorum	0	5.6	0
Hordeum spontaneum	3	4.8	6.4
Plantago coronopus	2.2	6.4	0.8
Poa bulbosa	24.2	78.4	47.2
Rostraria cristata	1.5	12	17.6
Total grasses	44.8	178.4	175.2
Anchusa aegyptiaca	0	0	0.8
Echinops polyceras	0	0	0.8
Phagnalon rupestre	0	0.8	0
Rhaponticum pusillum	0	0	3.2
Salvia sp.	0	0.8	1.6
Total shrubs	0	1.6	6.4
Total density (plants/m^2)	99.2	493.6	540

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