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Effects of exotic and endogenous shrubs on understory vegetation and soil nutrients in the south of Tunisia

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Abstract: This study was conducted in southern Tunisia in the growing seasons of 2013 and 2014, and aimed to compare the effects of exotic and endogenous shrub species (*Haloxylon persicum* and *Retama raetam*, respectively) on understory vegetation and soil nutrients. For each shrub species, the canopied sub-habitat (under the shrub crown) and un-canopied sub-habitat (in open grassland area) were distinguished. The concentrations of soil nutrients (organic matter, total nitrogen and extractable phosphorus) were found to be significantly higher ($P<0.05$) under *R. raetam* canopy than under *H. persicum* canopy and in open area. The result also showed that the presence of shrubs improved all the values of understory vegetation parameters (floristic composition, density, total plant cover and dry matter) and all these values were significantly higher under endogenous species canopy than under exotic species canopy. These results highlighted the positive effect of endogenous shrubs on understory vegetation and soil nutrients compared to the exotic ones in the Saharan areas of Tunisia.

Keywords: Saharan environment; invasive species; endogenous species; vegetation; soil enrichment

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Biological invasion is now considered one of the main threats to the world's biodiversity (Mooney and Hobbs, 2000). Exotic species are widely planted in tropical countries for industrial purposes as well as for re-forestation. However, ecological implications of such practices are often questioned (Poore and Fries, 1985). For instance, Vitousek et al. (1997) and Wilcove et al. (1998) reported that invasive non-native organisms have come to be recognized as one of the most serious current causes of plant species decline. The Mediterranean ecosystems, which contain 20% of the known plant species in the Earth (Cowling et al., 1996), are particularly threatened by plant invasions (di Castri et al., 1990). The Mediterranean islands are particularly vulnerable to plant invasions, and the impacts of plant invasions on plant diversity may be especially severe because these islands comprise major centres of plant diversity (Davis et al., 1994; Delanoë et al., 1996). At the ecological level, the spread of exotic plants in natural and semi-natural habitats may often be associated with a decline of native plant diversity (Richardson et al., 1989; Pyšek and Pyšek, 1995; Dunbar and Facelli, 1999; Levine et al., 2003), although this relationship is somewhat controversial (Alpert et al., 2000). Moreover, some studies reported that an important number of exotic plant species has toxic compounds, with negative effects on the survival and abundance of native plant species (Del Moral and Muller, 1969; Al-Naib and Al-Moussawi, 1976; Jayakumar et al., 1990; Lisanework and Michelsen, 1993; Noumi et al., 2009). That's why many land managers and restoration practitioners desire to create communities of native plant species to resist further invasion of exotic species.

Studies on arid Mediterranean-type ecosystems mainly concentrated on floristic structure, composition and species distribution in natural communities (Le Houérou, 1969; Jauffret and Lavorel, 2003; Abdallah

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et al., 2012; Noumi et al., 2012). Despite the importance of invasions in arid Mediterranean-type ecosystems, little is known about the underlying causes of these invasions and their consequences for native species and ecosystem functioning, especially, when introduction of invasive species is involuntary. The introduction of woody plants for the restoration of degraded arid and semiarid ecosystems has become increasingly important worldwide as a measure to protect soils (Castillo et al., 1997), combat desertification (Reynolds, 2001), supply natural resources (Guevara et al., 2003) and therefore, increase plant cover and species diversity (Cortina and Maestre, 2005). However, very few researchers have performed manipulative field experiments to dissect the net effects of woody species on soil nutrients and the characteristics of understorey vegetation in Mediterranean arid and semiarid areas (Maestre and Cortina, 2003; Abdallah et al., 2008). This knowledge is necessary to understand community dynamics and to develop sound management programs.

In this study, we focused on the effects of two shrubs species (exotic and endogenous) on understory vegetation and soil nutrients. *Retama raetam* (a leguminous shrub up to 3 m tall) is an endogenous species in northern Africa and the Middle East. *Haloxylon persicum* (a chenopod shrub up to 4 m tall), surviving in prohibitive environments, is termed a super-xerophyte species because of its extreme drought tolerance. Therefore, this species has been particularly favored as a pioneer plant to stabilize sand dunes, prevent soil desertification, conserve water and soil, and improve the environment under conditions that fewer large shrubs can tolerate for wildlife. *H. persicum* is also a palatable species for livestock and an excellent plant material to investigate the physiological characteristics of stress adaptation. It was introduced voluntarily to the Saharan region of Tunisia from the cold desert of Central Asia, for the objective of sand dune fixation without considering the ecological consequences of this exotic species. Since then *H. persicum* is being a dominant species covering vast areas in Tunisia.

Therefore, the main objective of this study was to assess the effects of exotic and endogenous plant species (*H. persicum* and *R. raetam*, respectively) on understory vegetation and soil nutrients compared with open spaces in an arid area of southern Tunisia. This study will help to select the optimal species (exotic or endogenous) that can be used as candidate species for ecological restoration in arid zones of Tunisia.

1 Materials and methods

1.1 Study area

The study was conducted in the eastern Great Oriental Erg of southern Tunisia, which is located in the Governorate of Kebili (9°00'42"E, 33°39'56"N). The mean annual precipitation was 50 mm during the study period (2013–2014). June, July and August are the driest months in a year. The mean monthly maximum temperature (July) is 42°C, while the mean monthly minimum temperature (January) is 7°C. The study site is characterized by a sandy soil (Derbel, 2012) and dominated by *Cleome ambliocarpa* Baratte & Murbeck (Capparaceae), *Helianthemum confertum* Dunal (Cistaceae), *Astragalus gombiformis* L., *Retama raetam* (Forssk.) Webb, *Anthyllis henoniana* Coss. (Fabaceae), *Henophyton deserti* Coss. and Dur. (Brassicaceae), *Calligonum polygonoides* L. (Polygonaceae), *Euphorbia guyoniana* Boiss. and Reuter (Euphorbiaceae), *Stipagrostis pungens* Desf. (Poaceae), *Ephedra alata-alenda* Batt. and Trab. (Ephedraceae), *Moltkiopsis ciliata* (Forssk.) I.M. Johnst (Boraginaceae), *Zygophyllum album* L.f. (Zygophyllaceae), *Haloxylon persicum* Bunge (Chenopodiaceae) and *Neurada procumbens* L. (Neuradaceae).

1.2 Experimental design

Our experiment was conducted during the growing season in spring 2013–2014. We selected two different shrub habitats with contrasted morphological traits to maximize the possible differences of the effects on understory vegetation and soil nutrients. For the species treatment, we designed ten 100 m×100 m sample plots with similar topography and soil features in each sub-habitat according to the method of Derbel (2012). In each plot, we randomly selected twenty individual shrub species and measured the height and canopy diameter (Table 1). A total of two hundred shrubs in each sub-habitat were randomly selected. For each shrub, we located a quadrat with area of 1 m×1 m beneath the canopy. We also designed forty sample plots in open areas located completely outside the shrubs.

Within each quadrat, we determined the understory floristic composition, species density (mean number of individuals of each species per quadrat), and total plant cover (%). Dry matter (DM; kg/hm^2) was assessed by the formula of Le Houérou (1982), as used by Abdallah et al. (2008): DM=r×43.1±3.6. Where r is the perennial plant cover.

Table 1 Heights and crown diameters of the two shrub species (mean±SE)

Shrub species	Height (m)	Crown diameter (m)
R. raetam	3.24±0.53	4.20±0.82
H. persicum	3.78±0.66	4.58±0.91

In parallel, we also investigated the effects of the two shrubs species on soil nutrients. Soil samples were collected from the topsoil layer of 0–10 cm, excluding litter and stones. The samples were air-dried and passed through by a 2-mm sieve for chemical analyses in the laboratory. Oxidizable soil organic matter (OM) was determined by the Walkly black procedure (Nelson and Sommers, 1982). Olsen's bicarbonate extraction (Olsen and Sommers, 1982) and Kjeldahl's method were used to analyze the extractable phosphorus (P) and total nitrogen (TN), respectively.

1.3 Statistical analysis

We evaluated the effects of sub-habitats on soil nutrients and understory vegetation by using one-way ANOVA, with the sub-habitat as the fixed factor. ANOVA analyses were conducted with SPSS 11.0. We also used Tukey's HSD test to perform pairwise comparisons when ANOVA showed significant differences between sub-habitats. Values of the probability lower than 0.05 were regarded as statistically significant.

2 Results

2.1 Soil nutrients under different sub-habitats

Measurements concerning soil nutrients were different, with higher values under canopied sub-habitats (Fig. 1). OM, TN and extractable P contents of soils under *R. raetam* canopy were higher than under *H. persicum* canopy and un-canopied sub-habitat. Differences of soil nutrients among different sub-habitats were statistically significant (Tukey's HSD-test at P<0.05).

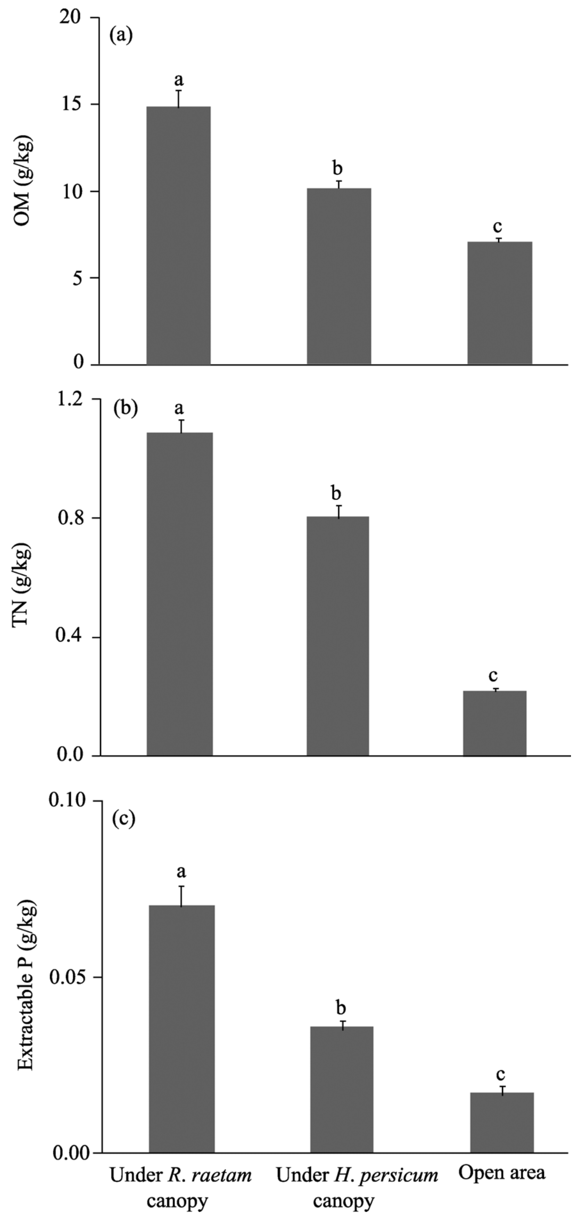

Fig. 1 Concentrations of organic matter (OM), total nitrogen (TN) and extractable phosphorus (P) of soils under *R. raetam* and *H. persicum* canopies and in open area. Different lowercase letters represent significant differences among different sub-habitats (Tukey's HSD-test at P<0.05).

2.2 Understory vegetation characteristics under different sub-habitats

The sample plots in this study had a total of 36 plant species, belonging to 34 genera and 20 families (Table 2). Species in Chenopodiaceae, Fabaceae and Asteraceae represented more than 40% of the species pool. In addition, results of the ANOVA (including the sample plots in open area) showed that the open patches had overall less floristic composition, species density, total plant cover and dry matter. Our results also showed that the presence of shrubs improves all the values of understory vegetation parameters (Table 3). The calculated dry matter was increased by 2.5 times for *R. raetam* and 1.5 times for *H. persicum* compared to un-canopied sub-habitat. Mean values of total plant cover were 18.87%, 24.57% and 43.31% in open area, under *H. persicum* and *R. raetam* canopies, respectively. Moreover, differences of total plant cover among different sub-habitats were statistically significant (P<0.05).

Table 2 Species density in the three types of sub-habitats (open area, under *R. raetam* and *H. persicum* canopies)

Species name	Family	Species density (individulas/m^2)		
		Under *R. raetam* canopy	Under *H. persicum* canopy	Open area
Anthemis stiparum	Asteraceae	3.15^a	2.80^a	1.34^b
Asteriscus hierochuntica	Asteraceae	2.45^a	1.50^b	0.00^c
Koelpinia linearis	Asteraceae	0.00^b	0.00^b	2.30^a
Launaea capitata	Asteraceae	2.80^a	2.62^a	0.00^b
Senecio gallicus	Asteraceae	3.26^a	0.00^c	0.92^b
Echiochilon fruticosum	Boraginaceae	4.40^a	0.00^c	1.20^b
Moltkiopsis ciliata	Boraginaceae	3.47^a	0.00^b	0.00^b
Henophyton deserti	Brassicaceae	0.00^b	1.12^a	0.90^a
Cleome ambliocarpa	Capparaceae	3.20^a	0.00^b	0.00^b
Silene villosa	Caryophyllaceae	6.22^a	2.88^b	0.70^c
Traganum nudatum	Caryophyllaceae	4.13^a	3.85^a	2.19^b
Anabasis articulate	Chenopodiaceae	3.54^a	1.42^b	0.00^c
Bassia muricata	Chenopodiaceae	1.70^a	1.50^a	0.44^b
Halocnemum strobilaceum	Chenopodiaceae	4.23^a	0.00^c	2.50^b
Haloxylon persicum	Chenopodiaceae	0.00^b	4.76^a	0.00^b
Haloxylon schmittianum	Chenopodiaceae	1.87^c	5.50^a	2.76^b
Traganum nudatum	Chenopodiaceae	0.00^b	3.50^a	0.00^b
Helianthemum confertum	Cistaceae	2.70^a	0.00^c	1.51^b
Ephedra altissima	Ephedraceae	0.00^b	1.88^a	0.00^b
Euphorbia guyoniana	Euphorbiaceae	4.17^a	0.80^b	0.00^c
Anthyllis henoniana	Fabaceae	1.76^a	0.00^b	0.00^b
Astragalis gombiformis	Fabaceae	4.45^a	2.50^b	0.00^c
Astragalis hamosus	Fabaceae	1.60^a	0.00^b	0.00^b
Hippocrepis cilita	Fabaceae	1.20^a	0.00^b	1.40^a
Lotus halophilus	Fabaceae	1.85^a	1.70^a	0.00^b
Retama raetam	Fabaceae	1.90^a	0.00^b	2.10^a
Erodium pulverulentum	Geraniaceae	0.60^a	0.00^b	0.52^a
Neurada procumbens	Neuradaceae	2.40^a	2.30^a	0.00^b
Plantago ciliata	Plantaginaceae	2.30^a	1.95^a	0.00^b
Limoniastrum guyonianum	Plumbaginaceae	3.67^a	0.00^b	0.00^b
Stipagrostis pungens	Poaceae	2.65^a	2.50^a	0.00^b
Calligonum polygonoides	Polygonaceae	2.20^a	0.00^b	0.00^b
Thesium humile	Santalaceae	4.88^a	0.00^b	0.00^b
Tamarix africana	Tamaricaceae	0.00^c	3.50^a	1.60^b
Daucus sahariensis	Umbelliferae	3.51^a	0.00^b	0.00^b
Zygophullum album	Zygophyllaceae	2.12^a	2.50^a	1.30^b

Note: Mean values which are not followed by the same letter are statistically significant among different sub-habitats (Tukey's HSD-test at P<0.05).

Table 3 Comparisons of dry matter, species density and total plant cover under *R. raetam* and *H. persicum* canopies and in open area

Parameter	Under *R. raetam* canopy	Under *H. persicum* canopy	Open area	*P*
Dry matter (kg/hm^2)	1,810±157.00^a	1,216±233.77^b	755.5±89.50^c	**
Species density (individuals/m^2)	12.37±2.10^a	5.25±0.90^b	3.60±0.32^c	**
Total plant cover (%)	43.31±0.25^a	24.57±0.17^b	18.87±0.12^c	**

Note: Mean values which are not followed by the same letter are statistically significant among different sub-habitats (Tukey's HSD-test at $P<0.05$). ** means significance at $P<0.01$ level.

3 Discussion

The effects of Mediterranean shrubs on their understory herbaceous vegetation have attracted much attention, and a variety of positive and negative effects have also been reported (Espigares et al., 2004; López-Pinto et al., 2006). The main purpose of this study was assessing the effects of two shrub species (invasive and endogenous) on soil nutrients and understory vegetation under Saharan bioclimate. Our study showed that soil fertility indices (OM, TN and extractable P) were significantly higher under canopy area of shrubs than in open area. Soils under woody canopies are more fertile than soils from the surrounding grassland (Belsky et al., 1989; Callaway et al., 1991; David et al., 2004; Abdallah et al., 2008, 2012; Noumi et al., 2012). In the same way, the study of Dohn et al. (2013) also revealed that woody plants tend to increase soil N and P concentrations beneath the canopy. A likely mechanism is that nutrient enrichment of soil under shrub canopy is a common phenomenon in arid ecosystems (Vetaas, 1992; Facelli and Brock, 2000; Titus et al., 2002). The increase of nutrient content in soil can be a result of an increase in plant litter amount, on the one hand, and a decrease in soil compaction, on the other hand (Xie and Wittig, 2004).

Overall, our results showed that the presence of shrubs improves all the values of understory vegetation parameters (i.e. floristic composition, species density, total plant cover and dry matter). Among the two shrub species, *R. raetam* had a stronger effect with higher values of understory vegetation parameters compared to the invasive shrub *H. persicum*. The recorded increase for the values of these parameters can be allotted to the high soil fertility under *R. raetam* canopy. The positive interactions, or facilitation, among plants is common in arid and semiarid ecosystems (Aguiar and Sala, 1999; Gómez-Sal et al., 1999; Tongway and Valentin, 2001), where the landscape often consists of patches of woody vegetation (mainly shrubs) embedded in a bare soil matrix (the 'open' patch type) that is sparsely populated with herbaceous vegetation. Numerous studies have shown that the establishment, abundance and fecundity of herbaceous plants are higher in the shrub patch than in the surrounding matrix (Tielbörger and Kadmon, 2000; Maestre et al., 2005; Badano et al., 2009). Such facilitation is mainly attributed to the engineering effect of shrubs, which improves the physical, chemical and hydrological conditions for herbaceous vegetation growing in shrub patches, compared with conditions in open patches (Pugnaire et al., 1996, 2004; Jones et al., 1997; Titus et al., 2002; Gilad et al., 2007; Badano et al., 2009). Patches of woody vegetation can also modify plant community composition and dynamics in drylands by trapping seeds and creating suitable microhabitats (Aerts et al., 2006). In this context, several studies in savannas have suggested that shade under woody species increases the understory herbaceous productivity due to the reduction of temperature and potential evapotranspiration (Vetaas, 1992; Díaz Barradas et al., 1999).

The exotic shrub (*H. persicum*), characterized by spread distribution, is successfully established on degraded areas of Tunisia. *H. persicum*, with the height of 2–4 m, has a large underground root system and photosynthesizes through small photosynthetic branches (Casati et al., 1999). *H. persicum* is scattered throughout northwestern China and northern Russia (Hadi and Kharazipour, 2008). In the Middle East, this species is mainly distributed in the Sinai Peninsula, Egypt, and central and northwestern Saudi Arabia on the Arabian Peninsula (Zohary, 1973). *H. persicum* is very tolerant to environmental extremes in temperature, light and water availability (Casati et al., 1999).

The strong competitive effect of Poaceae and Chenopodiaceae was well documented, and soil moisture measurements showed that water is less available under canopy areas of shrubs than in open patches (Davis et al., 1998; Forseth et al., 2001; Facelli and Temby, 2002).

4 Conclusion

The results of this study showed the positive effect of endogenous plant species on understory vegetation and soil nutrients in arid ecosystems of Tunisia. The net effect of shrubs on their own environment, whether it is positive or negative, is strongly dependant on the species itself. In view of the fact that *R. raetam* is an endogenous species, it is not surprising that the species shows the strongest positive effect on soil fertility and understory vegetation. Thus, it seems to be more useful as a restoration species in the arid areas of Tunisia and more suitable to create islands of resources and foster succession than the other investigated shrub species.

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