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Using trees as a restoration tool in Tunisian arid areas: effects on understorey vegetation and soil nutrients

K. Jeddi[A] *and M. Chaieb*[A,B]

[A]Department of Biology, Faculty of Sciences, University of Sfax, 3000 – B.P. 1171 Sfax, Tunisia.
[B]Corresponding author. Email: mohamed.chaieb@gnet.tn

Abstract. A field experiment was conducted in an afforested *Stipa tenacissima* L. steppe in arid southern Tunisia to evaluate the effect of three tree species (*Acacia salicina* Lindl., *Pinus halepensis* Mill. and *Eucalyptus occidentalis* Endl.) on understorey vegetation and soil nutrients. For each tree species, two subhabitats were distinguished: under the canopy, and out in the open. Organic carbon, total N, available P and pH were higher under the canopies of the three tree species than out in the open, and the effect was more pronounced in the top 10 cm of soil. Similarly, plant cover, biomass, richness and diversity were significantly higher under tree canopies. Some species such as *Plantago amplexicaulis* Cav., *Helianthemum kahiricum* Del. and *Artemisia campestris* L., which use large amounts of soil nutrients, showed a strong preference for areas under the canopy. Among the three tree species, *Acacia salicina* had the strongest positive effect on soil nutrients and understorey vegetation, and, thus, may be more useful for restoring arid areas and creating areas of enhanced soil nutrients than *Pinus* or *Eucalyptus*.

Additional keywords: arid ecosystem, restoration, soil fertility, subhabitat, vegetation dynamic, woody plants.

Introduction

In arid and semi-arid environments, trees are usually found within a grassland matrix, and different species have different effects on soil resources and understorey vegetation. This is especially important in these areas, since positive and negative interactions are the main drivers of plant community dynamics and ecosystem processes (Callaway 1995). Pugnaire *et al.* (2004) predicted that interactions between overstorey and understorey plants depend on how the different species modify their environment. Negative interactions can be the result of competition, allelopathy, increased soil salinity and caliche formation (Scholes and Archer 1997; Whitford 2002), and positive interactions may result from protection from pathogens and herbivores, increased resource availability and amelioration of soil conditions (Callaway 1995). Indeed, under individual tree canopies, soils usually have higher concentrations of organic matter, available N and other important nutrients, better physical structure, and faster water infiltration than soils in the open areas (Belsky *et al.* 1989; Rhoades 1996; Wilson 2002; Abule *et al.* 2005). Furthermore, tree canopies directly reduce solar radiation, evapotranspiration and soil temperatures (Ludwig *et al.* 2004), thus, promoting conditions that benefit subcanopy vegetation (Whitford 2002).

The use of woody plants for restoring degraded arid and semi-arid ecosystems has become increasingly important worldwide, as a measure to protect soils (Castillo *et al.* 1997), combat desertification (Reynolds 2001), supply natural resources (Guevarat *et al.* 2003) and, thereby increase plant cover and species diversity (Cortina and Maestre 2005). However, in Mediterranean arid and semi-arid areas, very few field-based studies have attempted to understand the net effects of woody species on soil properties and understorey vegetation dynamics (Maestre and Cortina 2004; Abdallah *et al.* 2008). This knowledge is necessary to understand ecosystem function and community dynamics in order to develop sound management programs. Woody species could be used for restoring degraded arid areas provided that they have a positive effect on ecosystem composition and function.

In this work, our objectives were to (i) evaluate the effects of three different tree species (*Acacia salicina* Lindl., *Pinus halepensis* Mill. and *Eucalyptus occidentalis* Endl.) on soil chemical properties (organic carbon, total N, total P, pH and electrical conductivity), and (ii) determine the effect (positive or negative) of each tree species on attributes of the understorey vegetation such as cover, richness, diversity and biomass, in an afforested *Stipa tenacissima* L. steppe in arid southern Tunisia.

Materials and methods

Study site

The study was performed in an exclosure called El Gonna (34°41′66″N, 10°30′22″E), located 20 km west of Sfax in Southern Tunisia (Fig. 1). Prior to fencing, the area had been used for summer rangeland grazing, mainly by sheep and goats, in an extensive grazing system. In 1995, 12 years before our study, the

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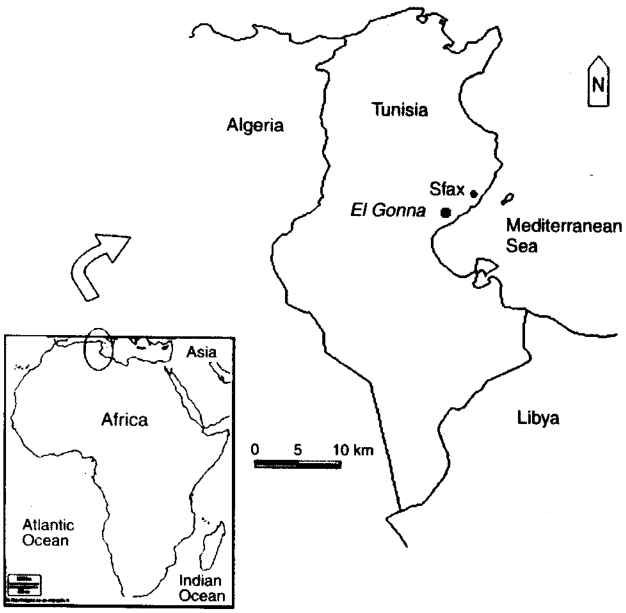

Fig. 1. Location of the El Gonna study site 20 km west of Sfax in south-eastern Tunisia, North Africa.

area was protected from grazing by the Forest Service (Forest General Direction) and planted to 1-year-old *Acacia salicina* Lindl., *Pinus halepensis* Mill. and *Eucalyptus occidentalis* Endl. seedlings. Average planting density was 300–500 trees/ha, resulting in an average tree spacing of ~6 × 5.5 m.

The climate is Mediterranean lower arid with temperate winters (Emberger 1954) with a mean annual precipitation of 196 mm. Temperatures range from an annual mean minimum of 2°C to a mean maximum of 24°C. The topography is mainly hilly (slopes 7–20°), and the soils are alkaline sandy loams, with friable caliche at 10–25 cm depth and outcrops of gypsum The area was occupied by an overgrazed *Stipa tenacissima* L. steppe, showing some indicator species of the presence of gypsum such as *Lygeum spartum* Loefl. ex L., *Atractylis serratuloides* (Sieb. ex Coss.), *Gymnocarpos decander* Forssk. and *Helianthemum lippii* ssp *intricatum* Murbeck and some plants such as *Artemisia herba-alba* Asso., reflecting vegetation recovery after grazing exclusion.

We would have preferred this study to have been conducted on more than one site because we are mindful of the issue of pseudoreplication (Hurlbert 1984). However, we were constrained by the availability of sites subjected to a common history of grazing, and where the three tree species were planted in close proximity.

Climatic conditions during the study period

During the hydrological year 2006–07, the mean annual rainfall recorded at El Gonna was ~263 mm (Table 1). Precipitation started with a moderate quantity during the month of September (24.5 mm) and, except for October and January (1.5 and 1 mm, respectively), it was well distributed throughout the growing season. Floret and Pontanier (1982) noted that in arid areas, only rains greater than 10 mm are efficient and beneficial for vegetation. Autumn (September–November) rainfall is important because it stimulates the germination of annual species and triggers the growth of the perennials.

Table 1. Monthly rainfall (in mm) recorded at El Gonna during the experimental year (2006–07; Commissariat Régional au Développement Agricole of Sfax)

Month	Rainfall (mm)
September	24.5
October	1.5
November	21
December	31.5
January	1
February	11.5
March	67
April	80
May	0
June	23
July	0
August	2
Total	263

Vegetation sampling

Our experiment was conducted during the spring 2006–07 growing season. We selected three 100 × 100 m plots similar in physiography and soil features and planted with *Acacia salicina*, *Pinus halepensis* and *Eucalyptus occidentalis*. At each of the study plots we randomly selected six individual trees and measured their height and canopy diameter (Table 2). We sampled in two subhabitats for each tree: beneath the canopy (at 50% radius), and outside of the canopy (at 150% radius; Fig. 2). At four aspects around each tree (N, S, E and W) we located four 1 × 1 m quadrats. Within each quadrat we measured plant cover of each understorey species. Cover <1% was arbitrarily set as 0.1% (Zhang 1998). Plant traits and nomenclature are based on work by Greuter *et al.* (1989) and Chaieb and Boukhris (1998). Species richness was measured as the average number of species per quadrat and diversity was calculated using the Shannon–Wiener index (H′). Biomass (dry matter) was assessed using the formula presented by Le Houérou and Hoste (1977), Le Houérou (1987) and Abdallah *et al.* (2008) where dry matter production (kg/ha) = 43.1 × cover of perennial plant species +3.6.

Soil sampling and analyses

Following vegetation sampling, soil samples were taken from the quadrats under the canopy and in the open at two depths, 0–10 and 10–20 cm. In the laboratory, the samples were air-dried and passed through a 2-mm sieve, ready for chemical analyses. Oxidable soil organic carbon was determined by using the

Table 2. Mean (±s.e.) of heights (m) and crown diameters (m) for the three tree species

Tree species	Height (m)	Crown diameter (m)
Acacia salicina	5.9 ± 0.31	3.32 ± 0.97
Pinus halepensis	3.1 ± 0.36	1.57 ± 0.53
Eucalyptus occidentalis	5.4 ± 1.17	2.33 ± 0.66

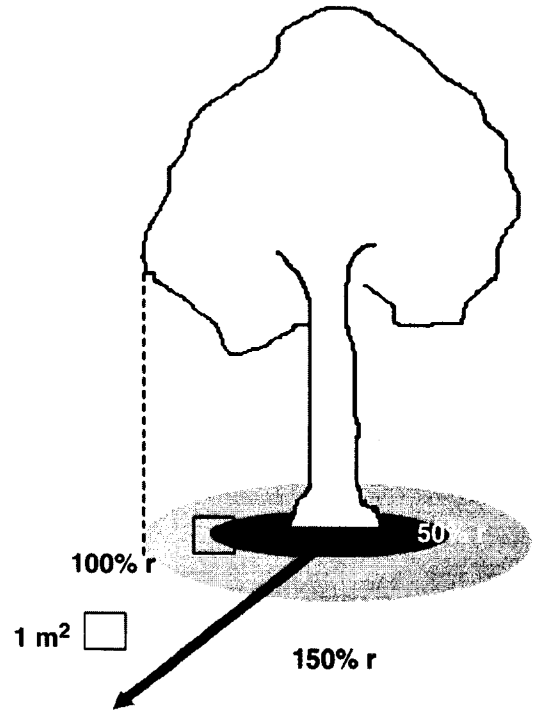

Fig. 2. Sampling design for data collection of the herbaceous layer underneath and outside the tree canopy. Sampling plots (1 × 1-m squares) were laid out at four aspects, N, S, E and W, at 50% canopy radius (r) and at 150% canopy radius for each tree. Soil samples were taken from squares under the canopy and out in the open, respectively.

Walkley–Black method (Nelson and Sommers 1982). The Kjeldahl method was used to analyse total N, and Olsen bicarbonate extraction (Olsen and Sommers 1982) to analyse extractable P. Soil pH and electrical conductivity (EC) were determined using a pH meter and conductivity meter, respectively (Van der Paw method, AFNOR 1987).

Statistical analyses

We evaluated the influence of tree species and subhabitat on the soil and vegetation parameters and their interactions with 2-way ANOVA using SPSS (11.0). When the ANOVA showed significant differences among the tree species, we used Tukey's HSD test to perform pairwise comparisons ($P < 0.05$).

Results

Plant cover, biomass, richness and diversity

Plant cover ranged from 75.6% under *Acacia salicina* to 59.3% under *Eucalyptus occidentalis* (Table 3). Cover was significantly different among all three tree species ($F_{2,38} = 6.65$, $P = 0.002$). Cover was always significantly greater under the canopy than in the open ($F_{1,38} = 34.4$; $P < 0.001$), and this was consistent among tree species (Species by subhabitat interaction: $P = 0.42$). Biomass followed the same trend, with a 1.5-fold increase, on average, under the canopy compared with in the open ($F_{1,38} = 38.1$, $P < 0.001$), and a consistent trend among all species (Table 3).

Species richness was similar among tree species ($P = 0.12$) but there was always ~1.5-times greater richness under the canopy than in the open ($F_{1,38} = 58.1$, $P = 0.001$). Similarly, H′ was greater under the canopy than in the open ($F_{1,38} = 3.09$, $P = 0.047$), but there were no differences among the three tree species ($P = 0.13$; Table 3).

Species composition

Subhabitat had a greater effect on cover of individual species than tree species (Table 4). The cover of *Artemisia campestris*, *Brachypodium pinnatum*, *Helianthemum kahiricum and Plantago amplexicaulis* were significantly greater under the canopy than in the open, and the effect was consistent among all tree species (Table 4). The cover of *Argyrolobium uniflorum*, *Polygonum equisetiforme* and *Retama raetam* was significantly greater under *Acacia salicina* than under the other tree species.

Soil properties

For all the tree species, soil organic carbon was always greater under the canopy than in the open ($F_{1,38}$ range = 60.5 to 80.5, $P < 0.001$, Table 5) but the canopy effect was significantly greater under *Acacia salicina* and *Pinus halepensis* (1.8 to 2.0-fold) than *Eucalyptus occidentalis* (1.5-fold; species by subhabitat interaction: $F_{2,44} = 6.7$, $P = 0.001$). Organic carbon concentrations were always greater at the surface ($F_{1,38} = 133.8$, $P < 0.001$) and the depth effect was greater for *Acacia salicina* than the other species (depth by species interaction: $F_{2,44} = 5.97$, $P = 0.003$). Similarly, total soil N was higher under the canopy than in the open ($F_{1,38} = 98.9$, $P < 0.001$), and the effect was greater for *Acacia salicina* than the other two species (species by subhabitat interaction: $F_{2,44} = 5.46$, $P = 0.005$). The significant decline in total N with depth ($F_{1,38} = 31.5$, $P < 0.001$) was

Table 3. Plant cover (%), biomass (kg/ha), species richness (plants/m^2) and Shannon–Wiener diversity index (H′) for *Acacia salicina*, *Pinus halepensis* and *Eucalyptus occidentalis* for under 'canopy' and out in the 'open' subhabitats

Tree species effects – cover: *Acacia* > *Pinus* > *Eucalyptus*, Biomass: *Acacia* > (*Pinus* = *Eucalyptus*). For a given species, canopy and opens were always significantly different at $P < 0.05$

Plant attributes	*Acacia salicina*				*Pinus halepensis*				*Eucalyptus occidentalis*			
	Canopy		Open		Canopy		Open		Canopy		Open	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Cover (%)	75.6	2.8	55.2	1.5	65.3	3.0	49.7	5.5	59.3	2.5	47.7	3.3
Biomass (kg/ha)	2811	37	1888	270	2240	148	1548	163	2032	93	1243	138
Richness (plant/m^2)	20.0	0.8	14.0	1.1	17.0	0.7	11.0	1.3	15.0	0.6	9.0	1.0
Diversity (H′)	3.2		2.3		2.9		2.1		3.0		2.1	

Table 4. Cover of herbaceous species (%) under the 'canopy' (C) and out in the 'open' (O) for the three tree species
Only significant effects are shown. Cover <1% was arbitrarily set as 0.1%

Species	*Acaciasalicina*			*Pinushalapensis*			*Eucalyptus occidentalis*			Species effect
	C	O	*P*-value	C	O	*P*-value	C	O	*P*-value	
Ajuga iva	0	0	–	1	0.1	–	0.1	0	–	–
Argyrolobium uniflorum	2	0.1	<0.05	0	0	–	0.1	0	–	<0.05
Artemisia campestris	3	0.1	<0.05	5	0	<0.01	2	0	<0.05	–
Artemisia herb-alba	15	17	–	18	12	–	24	23	–	–
Atractylis carduus	0	0.1	–	0	0	–	2	2	–	–
Atractylis serratuloides	1	0	–	0.1	0.1	–	0	0	–	–
Brachypodium pinnatum	3	0	<0.05	2	0.1	<0.05	2	0	<0.05	–
Bromus madritensis	0	1	–	0	0	–	0.1	0.1	–	–
Cynodon dactylon	3	6	–	1	0	–	2	0.1	–	–
Deverra tortuosa	8	6	–	2	5	–	0	2	–	–
Diplotaxis harra	5	10	–	4	3	–	3	8	–	–
Echium pycnanthum	0.1	0	–	0	1	–	0	0	–	–
Erodium glaucophyllum	15	9	–	13	7	–	12	6	–	–
Erodium hirtum	1	0.1	–	0.1	0	–	0.1	0	–	–
Euricaria pinnata	0	0.1	–	1	1	–	0.1	0	–	–
Fagonia cretica	3	2	–	5	7	–	5	9	–	–
Gymnocarpos decander	3	0.1	–	2	0.1	–	0.1	0	–	–
Helianthemum kahiricum	7	0.1	<0.01	5	0.1	<0.01	4	1	<0.05	–
Helianthemum sesseliflorum	1	0	–	0	0	–	0.1	0	–	–
Hyparhenia hirta	1	0.1	–	1	1	–	0.1	0	–	–
Kickxia aegyptiaca	2	1	–	0.1	0.1	–	0	0.1	–	–
Koleria pubescens	0.1	5	–	0	0.1	–	0	0	–	–
Launea quercifolia	1	0.1	–	2	3	–	0	0	–	–
Lygium spartum	0	2	–	0.1	1	–	0	0	–	–
Medicago minima	0.1	0.1	–	0.1	1	–	1	0.1	–	–
Plantago amplexicaulis	7	3	<0.05	7	2	<0.05	5	1	<0.05	–
Polygonum equisiteforme	2	0.1	<0.05	0	0	–	0	0	–	<0.05
Reichardia tingitana	1	1	–	1	1	–	1	0.1	–	–
Retama raetam	3	0.1	<0.05	0	0	–	0	0	–	<0.05
Rhus tripartita	0	0	–	0	0	–	0	1	–	–
Salvia aegyptiaca	2	1	–	1	2	–	3	1	–	–
Scorzonera undulata	2	2	–	2	2	–	0	0	–	–
Stipa capensis	7	5	–	6	11	–	11	7	–	–
Stipa tenacissima	4	6	–	3	2	–	2	2	–	–
Teucrium pollium	0	0	–	1	2	–	0.1	1	–	–

Table 5. Total organic carbon (OC, %), total nitrogen (N, mg/g), total phosphorus (P, mg/kg), pH and electrical conductivity (EC, us/cm) for *Acacia salicina*, *Pinus halepensis* and *Eucalyptus occidentalis* for under the 'canopy' and out in the 'open' subhabitats
Sub-habitat effects were significant for all soil parameters except electrical conductivity. Tree species effects: OC: *Acacia* = *Pinus* < *Eucalyptus*, N and P: *Acacia* > (*Pinus* = *Eucalyptus*). There were no significant tree species effects for pH and EC

Soil property	Soil depth (cm)	*Acacia salicina*				*Pinus halepensis*				*Eucalyptus occidentalis*			
		Canopy		Open		Canopy		Open		Canopy		Open	
		Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Organic carbon (%)	0–10	1.54	0.07	0.78	0.08	1.34	0.05	0.73	0.05	1.02	0.06	0.70	0.04
	10–20	0.87	0.04	0.62	0.04	0.73	0.04	0.63	0.03	0.77	0.03	0.64	0.03
Total N (mg/g)	0–10	1.24	0.07	0.57	0.05	0.93	0.02	0.56	0.04	0.90	0.08	0.57	0.07
	10–20	0.80	0.03	0.47	0.03	0.72	0.15	0.54	0.05	0.63	0.03	0.45	0.07
P (mg/kg)	0–10	55.4	1.32	44.4	1.35	51.0	1.30	44.2	1.41	51.1	1.16	43.4	1.32
	10–20	52.1	1.60	44.5	1.75	51.3	1.40	40.2	1.46	47.1	1.33	43.4	1.45
pH	0–10	8.17	0.02	7.89	0.05	8.02	0.08	7083	0.06	8014	0.03	7086	0.02
	10–20	8.01	0.03	7.70	0.05	7.96	0.03	7093	0.04	8.09	0.02	7.96	0.01
EC (dS/m)	0–10	1.29	0.03	1.16	0.08	1.37	0.02	1.17	0.07	1.36	0.05	1.01	0.06
	10–20	0.88	0.04	0.88	0.06	0.82	0.06	0.78	0.01	0.84	0.05	0.85	0.03

consistent among tree species. The mean values of available P were significantly higher under tree canopies ($F_{1,38}=93.7$, $P<0.001$) and overall, P was greater under *Acacia salicina* than under the other species ($F_{2,38}=4.46$, $P=0.012$).

Mean values of pH were significantly higher under the canopy for all species, but the effect was significantly greater under the canopy of *Acacia salicina* (subcanopy by species effect: $F_{2,44}=3.98$, $P=0.02$; Table 5). There were no differences in pH with depth. Electrical conductivity was consistently greater under the canopy than out in the open ($F_{1,38}=25.9$, $P<0.001$) for all tree species, and decreased substantially with depth ($F_{1,38}=137.6$, $P<0.001$).

Discussion

Effect of subhabitat on vegetation

The increase in total plant cover and biomass under tree canopies in our study is in agreement with previous work showing increases in these attributes beneath tree canopies in drylands (Belsky *et al.* 1989; Abdallah *et al.* 2008). In these environments, isolated plants act as obstructions for water, organic matter, nutrients, sediment and seeds carried by runoff water and wind (Belsky *et al.* 1989). These conditions create microhabitats suitable for herbaceous growth, increase productivity, and modify plant community composition and dynamics (Whitford 2002; Cortina and Maestre 2005). Tisdall and Oades (1982) noted that the maintenance of plant cover under tree canopies contributes to nutrient cycling and to the stability of soil aggregation, and ensures protection against soil erosion. In the present study, the positive effect of the tree canopy favoured species such as *Plantago amplexicaulis*, *Helianthemum kahiricum* and *Artemisia compestris*. These perennial species have well-developed root systems and the ability to use large amounts of water and soil nutrients (Long 1954). Furthermore, the cover of *Brachypodium pinnatum* was higher under the canopy than out in the open. Corcket *et al.* (2003) noted that the improvement in soil resources induced by shade enhanced reproduction and growth of this annual grass species.

The Shannon–Wiener index (H′) was greater under the canopies than out in the open. These results agree with those by Akpo and Grouzis (2004), who found a positive effect of trees on understorey vegetation diversity in Senegal. According to these authors, this means that the distribution of species is regular enough in this environment (i.e. under canopies), and, therefore, the ecological stability is more important than elsewhere.

Effect of tree species on vegetation

Our results showed that among the three tree species, *Acacia salicina* had the strongest positive influence on understorey vegetation. *Acacia salicina* is an Australian leguminous shrub or small tree introduced to many regions as a multi-purpose species (Le Houérou 1986; Rehman *et al.* 1999), and successfully establishes on degraded areas (Grigg and Mulligan 1999). The increased soil fertility, mainly total N, associated with *Acacia salicina* may favour the presence of some nitrophilous species such as *Polygonum equisetiforme*, and some leguminous species such as *Retama raetam* and *Argyrolobium uniflorum*, which use the amount of soil nutrients under the tree canopy. The improvement of soil fertility under this tree species, and particularly the accretion of organic matter, is apparently the primary source of understorey vegetation growth (Pugnaire *et al.* 2004).

Pinus halepensis seems to follow *Acacia salicina* as an understorey vegetation improver. It is a widely distributed tree species throughout the Mediterranean basin, where it is one of the few native tree species that can thrive under arid and semi-arid conditions (Maestre and Cortina 2004). The effect of *Pinus halepensis* plantations on the dynamics of natural regeneration is currently a topic of interest (Maestre and Cortina 2004). Observations and empirical data from semi-arid *Pinus* stands indicate that this species facilitates the development of the herbaceous understorey through improvement in soil conditions and microclimate (Bautista and Vallejo 2002; Maestre *et al.* 2003). However, Chirino *et al.* (2001) reported that, in semi-arid south-eastern Spain, an area planted with *Pinus halepensis* differed very little with respect to total plant cover and species richness from unplanted areas.

Of the three species assessed, *Eucalyptus occidentalis* was associated with the lowest understorey cover, diversity, richness and biomass. *Eucalyptus occidentalis* is an Australian tree species that has been used extensively for afforestation in arid areas of the Mediterranean basin, as it provides high quality wood and is highly resistant to drought and salinity (Lovenstein *et al.* 1991). *Eucalyptus* species usually support less understorey vegetation than other types of vegetation cover (Rosa *et al.* 1986). Indeed, Shiva and Bandyopadhyay (1983) noted that the strong development of the *Eucalyptus* root system reduced available water for understorey species, and that the tree's allelopathic properties restricted their germination, particularly in low rainfall areas. In our study, the effect of tree species on species richness and vegetation diversity was not clearly apparent. Other studies conducted on numerous sites have shown small tree species effects on vegetation diversity (Hong *et al.* 1997). However, the slight decrease in *Pinus* understorey vegetation diversity, as observed elsewhere (Fahy and Gormally 1998), can be explained by the sensitivity of some plants to thick litter layers and shady conditions encountered under coniferous stands (Augusto *et al.* 2003).

Effect of subhabitat on soils

Soils under tree canopies are often referred to as 'islands of fertility' because conditions are better in their immediate surroundings than areas away from the canopy (Reynolds *et al.* 1999). In the present study, our results showed that the three tree species had higher concentrations of organic carbon, total N and P than areas away from the canopy. This is consistent with results elsewhere (Abule *et al.* 2005; Zhao *et al.* 2007). However, the question of the source of soil enrichment under tree canopies remains largely unexplained. Belsky and Canham (1994) indicated that there may be several factors that contribute to the formation of these fertile islands. One of the most important factors is the nutrient inputs by tree litter (Belsky *et al.* 1989; Amundson *et al.* 1995). Litterfall inputs are relatively low in drylands owing to constraints in plant productivity (Berg *et al.* 1999), but they may be substantially higher immediately beneath the canopy (Cortina and Maestre 2005). Furthermore, Abdallah *et al.* (2008) suggested that the droppings from birds under tree canopies were one of the major inputs of nutrients. Differences in cover and dry matter production of herbaceous plants between tree canopies and the open may also exacerbate these differences in soil nutrients (Whitford 2002).

Contrary to other findings (Belsky *et al.* 1989; Hagos and Smit 2005), we recorded higher soil pH under tree canopies than out in the open. Comparable results were reported by Abule *et al.* (2005) and Abdallah *et al.* (2008), who also recorded a higher pH in canopied subhabitats than in the open area. The exact reasons for differences in soil pH are unknown, although greater pH under the canopy is consistent with higher levels of exchangeable cations under tree canopies (Eldridge and Wong 2005).

Effect of tree species on soils

In our study, tree species differed in their effects on soil properties, and there was a significant depth effect on soil organic carbon across all species, with the strongest effects under *Acacia salicina*. This can be explained by the ability of leguminous species to fix atmospheric nitrogen, which could result in higher soil fertility (mainly soil N content) in comparison with non-leguminous species (Wezel *et al.* 2000; Caravaca *et al.* 2003). Soil fertility may also be influenced by litterfall, throughfall and the mineral composition of stemflow, which varies with tree species (Parker 1983).

In general, past research has shown increases in organic matter and nutrients in the topsoil beneath hardwood species and reductions beneath *Pinus* (Challinor 1968). However, soil fertility under *Pinus halepensis* in our study was marginally greater than under *Eucalyptus occidentalis*. This may be due to the presence of fungi beneath *Pinus*. Indeed, when fungi and bacteria are present in the soil, they indicate elevated levels of available nutrients and higher mineralisation rates in the surface layers (Tongway and Hindley 1995; Aguilera *et al.* 1999). Furthermore, the leaf litter of *Eucalyptus* species does not readily contribute to humus formation and infiltration of water into underground cavities. However, Eldridge and Freudenberger (2005) found that *Eucalyptus* species increased infiltration in fine textured soils, but not in coarse textured soils. The lack of humus affects its contribution to soil fertility (Shiva and Bandyopadhyay 1983). However in grazed pastures of south-eastern Australia, significant *Eucalyptus* canopy effects have been observed in the surface soil layers, with elevated soil pH, carbon, and nutrients inside the area occupied by the tree canopy, indicating soil enrichment in a zone around the tree (Eldridge and Wong 2005; Wilson *et al.* 2007).

In our study, organic carbon, N, P and EC all decreased with increasing depth, consistent with reports from the Middle Awash Valley of Ethiopia where soil nutrients and EC were concentrated in the first centimetres of soil under the canopy (Abule *et al.* 2005). In general, the results are also consistent with a decline in nutrients with depth for a large number of studies of tree effects on soil nutrients (e.g. Eldridge and Wong 2005), though some studies (e.g. Rhoades *et al.* 1998) did not detect changes in nutrients with depth under tree canopies.

Conclusions

The results of this study confirm the positive effect of woody plants on understorey vegetation composition and diversity in an arid ecosystem. This positive effect can mainly be ascribed to some understorey species such as *Plantago amplexicaulis*, *Helianthemum kahiricum* and *Artemisia campestris*, which are known for their ability to use large amounts of soil nutrients, and, therefore, showed a strong preference for canopy sites. The positive influence of a canopy compared with an open site was also apparent for soil organic carbon, total N, available P and pH. Our results demonstrate a significant effect of tree species on surface soil properties for a 12-year-old plantation. These rapid changes in soil properties were probably favoured by the generally low levels of fertility in the study area. We note that soil enrichment was mainly restricted to the top 10 cm of soil, which is commonly more sensitive to changes in plant cover.

Using woody species as a restoration tool can be an important strategy to combat desertification and degradation in arid and semi-arid areas. Their use in restoration must be carefully evaluated, however, and consider their effects on microhabitats. Further, their role as potential weeds must be carefully balanced with their positive effect on soils and plants. Outside their natural range, both *Acacia salicina* and *Eucalyptus occidentalis* may induce negative effects on community composition and ecosystem functions. However, the use of *Acacia salicina* can be important because it is used for fodder production, fuel, furniture construction and tannin production, apart from its positive effects on soil and vegetation. The invasive potential of these tree species could be minimised by reducing the rotation period and favouring management practices aimed at controlling their spread.

Further research and controlled experiments are necessary to obtain more definitive results on the use of these tree species for restoration. We recommend that caution be exercised in extrapolating our results to other arid rangelands as this work was conducted at only one site.

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