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Land restoration by fodder shrubs in a semi-arid agro-pastoral area of Morocco. Effects on soils

Claudio Zucca [a,*], Francesca Julitta [b], Franco Previtali [b]

[a] Dipartimento di Ingegneria del Territorio – Nucleo Ricerca Desertificazione (NRD), University of Sassari, Viale Italia 39, 07100 Sassari, Italy
[b] Dipartimento di Scienze dell'Ambiente e del Territorio (DISAT), Università degli Studi di Milano-Bicocca, Piazza della Scienza 1, 20126 Milano, Italy

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ABSTRACT

The present study assesses the effects of *Atriplex nummularia* Lindl. growth on soil chemical properties in a semi-arid area. The area is located in the Marrakech province (Morocco), in a degraded agropastoral region subjected to soil restoration actions based on fodder shrub plantations.

Three plantations of different age (1995, 2000, 2001), conducted in three different sites, were investigated. In each site, three plots with different degree of plant development (Good, Medium, Poor), were chosen. Three under-canopy (Uc) and three between-plants (Bp) minipits were sampled (0–10 cm and 10–20 cm) and analysed in each plot, for a total number of 54 minipits. Statistic analysis was carried out to check the significance of the observed Uc–Bp average differences.

A significant increase under canopy was observed in soil Sodium Adsorption Ratio (SAR; +139%) and OC (+32%) in the top layer (0–10 cm). The overall effects of the plantations on soil quality are discussed.

1. Introduction

Fodder shrubs have been extensively used in dry regions to mitigate the effect of drought and desertification and to rehabilitate land productivity in degraded rangelands (Le Houérou et al., 1991). Halophytic forage shrubs such as saltbush (*Atriplex* spp.) are grown in a range of saline and arid environments, where they are generally used to fill annual feed shortages within grazing systems (Le Houérou, 1992; Papanastasis et al., 2008).

During the last decades *Atriplex nummularia* Lindl. ("Oldman Saltbush"), native to Australia, has been one of the most appreciated fodder shrubs in various regions of the world, from Australia, to Latin America, North Africa and Western Asia (Aganga et al., 2003; Ben Salem et al., 2010; Guevara et al., 2005; Le Houérou, 1994, 2000; Mulas and Mulas, 2007; Vallance, 1989). This species, a deep rooted perennial shrub, has proven to be well adapted to arid conditions, and is appreciated for its tolerance to aridity, salinity, and direct grazing (Correal et al., 1990; Gates and Muirhead, 1967). It is palatable for the livestock and provides a high fodder production and an all-year grazing of green biomass (Le Houérou, 1994). Altough *A. nummularia* is a halophyte, the presence of high salt levels in the soil does not seem to be required for its optimal growth (Ramos et al., 2004). It is known that *A. nummularia* plants actively accumulate soluble salts in leaves, especially sodium, in association with a drought tolerance mechanism (Ramos et al., 2004; Sharma et al., 1972). For this reason it is also considered as an excellent species for reducing soil salinity in drylands, if cut and collected (Ben Salem et al., 2005).

The plant litter can thus modify the top soil salinity, along with other soil properties. A few studies are available on the effects of *A. nummularia* on soils. Among these, Sharma and Tongway (1973), Sharma (1973), Sameni and Soleimani (2007) studied the distribution of salinity and of some soil physico-chemical properties under and between the plants, observing significant changes in salinity and pH. Cepeda-Pizarro et al. (1992) and Maganhotto de Souza Silva et al. (2008) focused on the plants effects on soils microbiological properties and micro-arthropods community respectively. Their findings will be discussed in greater detail in the discussion chapter.

The purpose of the present research was to assess the impacts of the *Atriplex* plantations on soil properties in a study site in Morocco. Since the early 1990s, *A. nummularia* was extensively introduced in some areas of the Marrakech region, in the context of the national strategies for rangeland rehabilitation carried out by the Moroccan government. Some thousands of hectares were planted in the Rural Municipality of Ouled Dlim (Marrakech), under the supervision of the DPA (Direction Provinciale de l'Agriculture), the local branch of the Ministry of Agriculture (Zucca et al., 2005).

The present work studies the effects of the plantations on a range of soil chemical properties, and especially on organic carbon and on the variables related to soil salinity, and thus to contribute to the evaluation of land restoration interventions in semiarid degraded lands.

* Corresponding author at: Dipartimento di Ingegneria del Territorio – Nucleo Ricerca Desertificazione (NRD), University of Sassari, Viale Italia, n. 39–07100 Sassari, Italy. Tel.: +39 079 2111016; fax: +39 079 217901.
E-mail address: clzucca@uniss.it (C. Zucca).

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2. Materials and methods

2.1. Study area

The study area is located in the Rural Municipality of Ouled Dlim, in Morocco, about 30 km North-West of Marrakech (Fig. 1). Its extent is around 570 km^2.

The climate of the area is semi-arid, with long warm dry season (April to October). The average annual rainfall referred to the last 30 years (1981–2010), as measured by the Ouled Dlim meteorological station, is 203 mm. The area is located in the central-western part of the Palaeozoic Jebilet, the most ancient relief of Morocco (Huvelin, 1970), and is characterized by metamorphic formations (mainly schists). The relieves are rounded, generated by long lasting geomorphologic processes (climatic water erosion) acting on the highly erodible formations. The erosion and accumulation pediments (*glacis*) are the most typical local landforms. Moderate water erosion is common in the northern side of the study area. Sometimes channelled erosion (gully) can be observed.

Soils are mainly shallow and eroded, rich to moderately rich in carbonates, saturated and sub-alkaline to alkaline. In some cases they show the evidence of past evolution: buried and truncated illuvial horizons, ancient calcrete surfaces and complex polycyclic profiles can be observed.

The area is traditionally interested by extensive pastoral activities and soils are highly degraded because of overgrazing. Cereals, especially barley and wheat, are also grown as fodder for livestock. The natural vegetation cover is sparse or absent. Woody plants are mainly represented by *Ziziphus lotus* (L.), locally named "Jujubier".

2.2. Experimental set-up

Three plantation sites (s1, s2, s3; Fig. 1) were chosen, based on plant age, land unit, and land management. The selected plantations were carried out in 1995, 2001 and 2000 respectively, being the oldest plantations in the study area, which increased the probability to observe the effects of the introduced plants on the soils. In the study area, the *Atriplex* plants usually become increasingly senescent after 8–10 years, and the maximum biomass production can be observed between 4 and 7 years after plantation. The three sites belong to different land units, as reported in Table 1. All plantation interventions were carried out by the DPA, using the same technique (an example of plantation is shown in Fig. 2). The planted seedlings aligned along contour furrows made by rippers. The distance between the plants was 3 m along the two cardinal directions, and the resulting average plant density was 816 plants per hectare. After plantation, livestock grazing was excluded for three years; later on, every year in autumn the closures were opened to direct sheep grazing. Stocking rates were variable and not recorded. The selected sites were interested by comparable agro-pastoral management, in order to exclude as far as possible the influence of this factor on plants development and soil properties.

Sampling was stratified according to the relative plant development. Based on visual observations and biometric measurements, and following the qualitative criteria proposed by Sghaier et al. (1994), sub-areas characterised by three different degrees of plant development were chosen inside each site. Experimental plots were then chosen and delimited in each sub-area, and respectively named as good (G), medium (M), and poor (P).

The nine selected plots have a surface of 15 × 15 m and include homogeneous sub-populations of 25 plants, 5 lines by 5 rows. The plots have regular surface and slope angle always below 5%, to reduce the variability linked to morphology, slope and aspect. In the central part of each plot, 6 minipits were dug: 3 between the plants (Bp), 3 under the canopy (Uc). The Bp minipits were equidistant from the 4 nearest plants. Uc minipits were dug in correspondence of the plants shadowing area and downwind with reference to the most intense winds. More precisely, at a distance of some decimetres from the stem, in the North-West direction, outside the "impluvium" area, disturbed by the plantation interventions. Two layers were sampled in each minipit: 0–10 cm (A) and 10–20 cm (B). Totally, 93 soil samples were collected in January 2007, 54 from A layers and 39 from B layers (the soils were in some cases too shallow to have a B layer). Litter was removed before sampling. The following laboratory analyses were made on soil samples (Julitta, 2007): particle size, by wet sieving and pipette method, according to the USDA textural classes: Clay (<0.002 mm), Silt (<0.05 mm), Sand (<2 mm); pH H_2O; pH KCl; pH in 1:5 solution (pH 1:5); Carbonates (Carb; gas-volumetric determination); Organic Carbon (OC; by elemental analyzer), total Nitrogen (N; by elemental analyzer); Electrical Conductivity in saturated extract (EC_{se}); Electrical Conductivity in 1:5 solution (EC 1:5); Saturation Percentage (SP; calculated with reference to the saturated extract); Salinity % (Sal; calculated according to US Salinity Laboratory Staff, 1954); Total Cations ($[Na^+]_{tot}$,

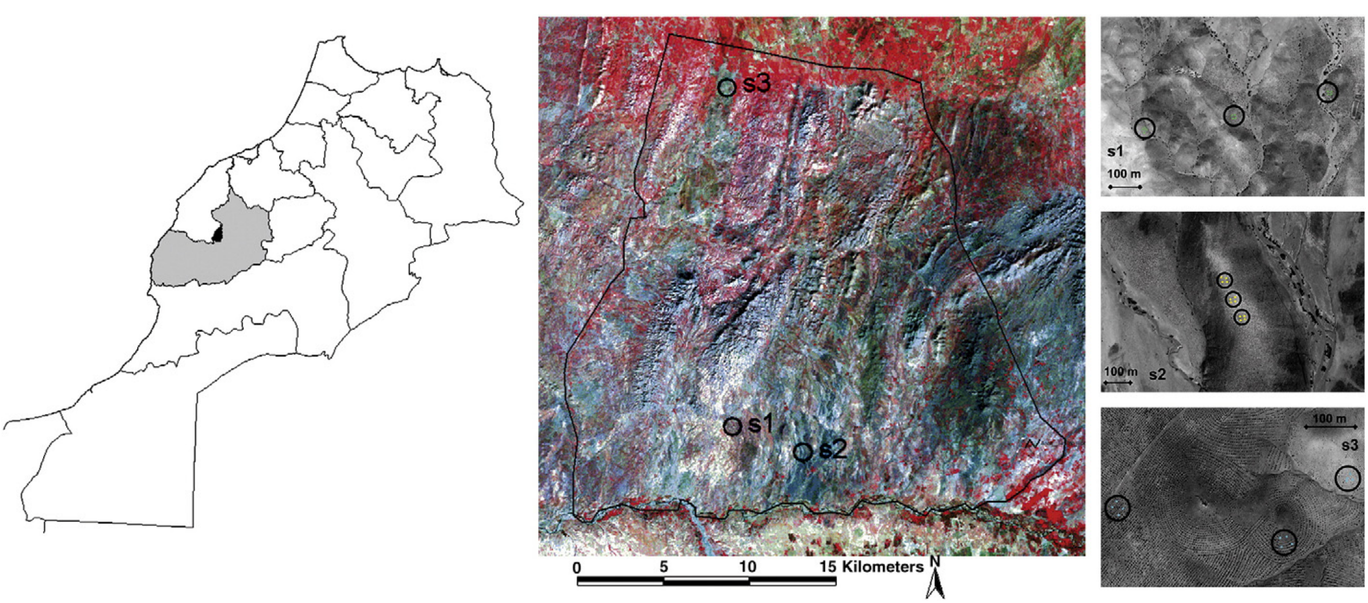

Fig. 1. Left and centre: the study area in the Rural Community of Ouled Dlim (Province of Marrakech, Morocco). The central image (LANDSAT data) shows the Jebilet relieves with their scarce vegetation cover. Right: the location of the selected sites (s1, s2, s3) and plots in the study-area, on an IKONOS panchromatic image.

Table 1
Description of the three studied sites (s1, s2, s3).

	s1	s2	s3
Site name and date of the plantation	Abda Skarna, 1995 to 1997	Kedadra, 2001	Sidi Haddi, 2000
Coordinates[a]	563900; 3515800	567700; 3514400	563500; 3535400
Bedrock and land unit[b]	Chloritoschist.	Clay-schist, encrusted by calcium carbonate at the surface.	Schist and sandstone substratum.
	Land unit G2 (s-facies).	Land unit G7	Land unit G2 (north-facies
	Erosion pediments (*glacis*) on alluvial or schist substrate. Moderate to gentle slopes gradually decreasing downslope. Moderate erosion, sometimes channelled. Vegetation cover by sparse shrubs. Presence of cereal crops.	Colluvial/alluvial substrate, and schist. Wide alluvial fans of different ages and geomorphic order. Gentle slopes Vegetation cover by very sparse shrubs. Presence of cereal crops.	Same as the south-facies, with more frequent colluvial and alluvial substrates and more developed soils, often subjected to accelerated erosion.
Soils[c]	Leptic LUVISOLS, Haplic CAMBISOLS, Lithic LEPTOSOLS	Leptic CALCISOLS Petric CALCISOLS Lithic LEPTOSOLS	Leptic LUVISOLS Haplic LEPTOSOLS
Other observed species	*Stipa retorta*, *Frankenia corymbosa*, *Ziziphus lotus*, *Schismus barbatus*	*Peganum harmala*, *Ziziphus lotus*	*Peganum harmala*, *Asphodelus tenuifolius*, *Ferula communis*

[a] Average coordinates (WGS84-UTM29N), for the whole site.
[b] Based on Zucca and Previtali (2007).
[c] According to WRB classification (FAO/ISRIC/ISSS, 2006).

Fig. 2. Panoramic view of an *Atriplex nummularia* plantation in one of the study sites (Abda Skarna site; Ouled Dlim, Marrakech).

$[K^+]_{tot}$, $[Ca^{2+}]_{tot}$, $[Mg^{2+}]_{tot}$; determined according to US Salinity Laboratory Staff, 1954); soluble cations ($[Na^+]_{se}$, $[K^+]_{se}$, $[Ca^{2+}]_{se}$, $[Mg^{2+}]_{se}$; measured in saturated extract by atomic adsorption); cations capacity exchange (CEC); base saturation (BS); exchangeable sodium percentage (ESP); and sodium adsorption ratio (SAR).

To quantify the plant canopy cover in each plot, the following biometric variables were recorded for each plant: maximum height (mh), maximum diameter along north–south direction (∅ N–S), Maximum diameter along east–west direction (∅ E–W). Canopy cover for individual plants was calculated as follows (Lailhacar et al., 1989):

$$\text{Canopy cover} = (\varnothing_{N-S}\varnothing_{E-W})\pi\,(4)^{-1}$$

2.3. Statistical analysis

The statistical analysis was carried out by comparing the average values of the variables of interest in Bp and Uc positions, layer by layer (A, 0–10 cm; B, 10–20 cm). The following soil properties were considered (OC, N, pH H_2O, pH KCl, ΔpH, Carb, EC_{se}, $[Na^+]_{tot}$, $[K^+]_{tot}$, $[Ca^{2+}]_{tot}$, $[Mg^{2+}]_{tot}$, $[Na^+]_{se}$, $[K^+]_{se}$, $[Mg^{2+}]_{se}$, $[Ca^{2+}]_{se}$, CEC, SAR, ESP The average values for the three Uc samples and for the three Bp samples were calculated in each plot and for each layer. A paired-samples *t* test ($\alpha = 0.05$) was applied per each position (nine values, one per plot, for both layers A and B). The number of treated samples was 54 in A (27 in both Uc and Bp) and 39 in B (21 in Bp and 18 in Uc).

A further elaboration was carried out by considering the best developed plantations only (three G plots and three M plots). In this case the average values of all the Uc and Bp samples were compared, layer by layer and an unpaired *t* test ($\alpha = 0.05$) was applied. The number of treated samples was 36 in A (18 in both Uc and Bp) and 29 in B (16 in Bp and 13 in Uc).

3. Results

Tables 2 and 3 respectively show the average values for canopy cover and for selected pedological variables in the nine plots.

The plant development ranges were relatively similar across sites, in terms of difference between the average canopy cover values of P and G plots (Table 2). The maximum canopy development is not associated to the plant age, and, as an example the highest values can be observed for the s3 G plot and not for s1 G (s1 is the oldest plantation). The maximum values are likely related to the station conditions, and probably even the younger plantations (6 and 7 years old) had reached their maximum development before the sampling date.

The descriptive soil data reported in Table 3 show the pedological variation between the three sites. The soils of the three plantations showed different values for pedological variables that are linked to the very stable soils characteristics, such as texture and carbonate content. Soils are clayey and sub-alkaline in s3, medium textured and rich in carbonates in s2, more sandy and alkaline in s1.

Table 4 reports the mean values for the studied chemical variables, according to the sampling position (Uc/Bp).

Seven variables yield significant differences if topsoil samples (A layer) are considered: OC (+32%), N (+9%), pH H_2O (+1.9%), $[Na^+]_{tot}$ (+47%) $[K^+]_{se}$ (+218%), CEC (+19%), SAR (+139%). Two significant changes were observed in B layer: pH H_2O (+4%) and ΔpH (+73%). Considering the well developed plots only (G+M), the following differences are significant in the A layer: OC (+40%), $[K^+]_{se}$ (+255%), SAR (+128%), while in the B layer we have: pH H_2O (+5.5%), ΔpH (+83%), EC_{se} (−60%), $[Ca^{2+}]_{se}$ (−72%).

4. Discussion

The analysis highlights the plant effect on OC, $[K^+]_{se}$ and SAR, which show an evident increase in the top layer. This trend is not confirmed by the B layer, indicating a direct input of soluble salts from the plant litter. The trend is followed by the increase in pH, especially in B, where it is paralleled by a decrease in salinity. The increase in ΔpH appears to be linked to a sharper increase of pH H_2O under canopy, as compared to pH KCl, which is more stable. The increase in CEC in A is correlated to OC.

The obtained results are partially in line with previous research. Sharma and Tongway (1973) studied the soil salinity distribution within a community of regularly spaced, ten years old Saltbush plants, in semi-arid conditions (with an annual rainfall of 380 mm and sub-acid to neutral soil pH). They highlighted significant higher salinity in the 0–15 cm soil layer and higher pH in the 0–7.5 cm layer beneath the bush canopy compared to between the bushes, and called this top layer "salt accumulation zone". In the same experimental site, Sharma (1973) also observed a significant increase in soluble Na^+, K^+, Mg^{2+}, and Ca^{2+}, higher SAR and higher levels of exchangeable sodium in the upper layer. The increase in salinity is reported as strongly correlated to chlorides of various cations. In our case the salinity does not increase significantly in the A layer, but decreases in the B layer. Sharma and Tongway (1973) also found that the salt accumulated in the surface layer ("accumulation layer") under the bushes is mainly derived from the underlying soil profile ("depletion layer"). In our case, the shallow soils and the experimental set-up (considering a maximum depth of 20 cm) do not allow to observe such a clear layering. It can be noted however (Table 4) that the $[Na^+]_{tot}$ values show an increase under canopy in the A layer (+47%) and a decrease in the B layer (−20%). Although the latter difference is not statistically significant, it may indicate an incipient redistribution process.

Partially contrasting results are reported by the literature. Sameni and Soleimani (2007) evaluated the effects of different *Atriplex* species, including *nummularia*, on under and inter-canopy soil, in a dry region in southern Iran. Their results showed an increase in EC, SAR and Na^+, but associated with a decrease of pH values.

Cepeda-Pizarro et al. (1992) compared soils under *A. nummularia* and under some autochthonous species in arid conditions in Chile (annual rainfall around 145 mm), but did not observe significant chemical differences in the top soil horizons under the different litters. They suggested that this could be related to the observed low litter decomposition rates.

As far as the effects of the plants on soil OC are considered, only the A layer samples showed a significant (and consistent) increase under canopy. This is in line with the results of Sharma (1973), who found a significant OC increase (+10% to +16%) only in the 0–7.5 cm layer and by Sameni and Soleimani (2007), who observed a higher OC and N increase in the 0–10 cm layer as compared to the 10–40 cm one. The work by Lailhacar et al. (1989) also confirmed that the significant relationships between soil properties and *A. nummularia* development can be mostly observed within the first 10 cm.

Table 2
Average canopy cover and standard deviations calculated in each plot based on biometric parameters (N–S diameter, E–W diameters) measured on each individual plant. Degree of plant development: G = good; M = moderate; P = poor. Canopy cover = $(\varnothing_{N-S} * \varnothing_{E-W})\,\pi\,(4)^{-1}$.

Plot	Canopy cover (m^2)	
	Av.	s.d.
s1 G	5.76	4.04
s1 M	2.99	0.78
s1 P	0.95	0.43
s2 G	4.71	1.39
s2 M	1.78	0.81
s2 P	0.98	0.62
s3 G	6.13	4.49
s3 M	3.03	2.36
s3 P	0.85	0.33

Table 3
Average and standard deviation values for selected pedological variables, in each plot (G = good; M = moderate; P = poor).

	OC (%)		N (%)		C/N		Sand (g kg^{-1})		Silt (g kg^{-1})		Clay (g kg^{-1})		pH H_2O		Carb (%)		CEC (meq 100 g^{-1})		EC es (dS m^{-1})		Sal (%)		SAR		ESP	
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.
s1G	0.57	0.32	0.12	0.02	4.77	2.45	572	46	276	37	152	34	8.7	0.3	10.8	2.8	13.19	2.12	2.15	1.54	0.2	0.1	2.4	3.0	4.5	2.4
s1M	0.58	0.41	0.09	0.03	5.73	2.04	592	23	267	20	141	11	8.7	0.2	4.7	1.5	12.12	3.26	1.81	0.83	0.2	0.1	1.5	1.3	8.9	10.7
s1P	0.43	0.08	0.11	0.01	4.12	0.96	610	61	189	35	201	41	8.0	0.2	3.4	0.9	15.72	3.62	1.51	1.53	0.1	0.1	0.8	1.2	2.19	1.13
s2G	0.39	0.18	0.11	0.01	3.52	1.47	516	16	319	17	166	27	7.7	0.4	16.9	1.8	9.50	0.78	16.63	8.84	1.9	1.1	2.2	1.6	20.0	18.2
s2M	0.51	0.21	0.12	0.01	4.33	1.49	522	39	326	34	153	28	8.0	0.1	16.2	2.3	10.64	1.25	4.38	5.46	0.5	0.7	2.1	3.3	18.0	19.4
s2P	0.50	0.16	0.11	0.01	4.73	1.46	522	30	328	20	150	26	8.0	0.2	17.0	3.3	10.34	1.07	1.75	1.95	0.2	0.2	1.3	2.6	5.0	7.4
s3G	0.76	0.15	0.18	0.01	4.74	1.70	337	65	307	94	356	120	7.9	0.2	4.8	2.0	24.44	7.19	8.83	6.25	1.2	0.9	2.2	2.3	5.2	4.3
s3M	0.54	0.14	0.14	0.01	3.82	0.88	513	51	233	31	254	34	8.0	0.2	4.0	2.3	13.84	2.24	1.10	0.77	0.1	0.1	0.4	0.2	3.8	1.3
s3P	0.36	0.12	0.12	0.01	3.22	0.66	503	47	195	35	302	41	7.4	0.3	1.5	0.5	15.77	4.09	3.54	4.57	0.3	0.5	1.3	1.2	3.0	1.2

Some variability was observed in the field from site to site (s1, s2, s3). Fig. 3 shows the average Uc and Bp values in the A layer for the three sites, considering all the G and M plot samples, and four variables (pH H_2O, OC, EC_{se} , SAR). In some cases trends are flatter or slightly contrasting in some sites (as for OC and SAR in s3, or pH in s1). A particularly marked Uc–Bp difference can be observed for OC in the s1 plot, which is the oldest (10 years old) plantation.

If the results are discussed in terms of impact of the plantations on the soil quality, they show a contrasted picture, where both organic carbon and alkalinity are increasing.

If we focus the discussion on the upper layer only (0–10 cm), + 32% was recorded for OC and + 139% for SAR. The average increase in OC is around 15 g kg^{-1} (on the fine earth). By taking 1.3 g cm^{-3} as a reference bulk density, and by assuming that the rock fragments (>2 mm) content can be as high as 50% and that the Uc soil samples can approximately represent 50% of the plantation area, an OC increase around 5 t ha^{-1} could be estimated. This amount could represent a significant result in view of the objectives of mitigating land degradation, considering the relatively short period of plant growth (ten years or less) and the dry climate of the study area, which favour a fast litter mineralization. Furthermore, the mean OC value in Bp position (0.48), is much lower than the average value (0.72) referred to about 60 samples coming from 25 profiles previously studied and distributed over the wider area represented in the central part of Fig. 2 (Zucca and Previtali, 2007). This confirms that most of the plantation interventions were made on relatively depleted and eroded soils. The recorded $[K^+]_{se}$ increase can be also considered as a positive effect on soil fertility.

On the other hand, the doubling of SAR values indicates a significant increase of sodium concentration in the soil solution, although the absolute value in Uc position (2.3) is not very high. The average ESP values (11.4 in Uc) are instead high, if considered that 15 is the conventional diagnostic limit for saline soils. Such values may affect the aggregate stability, if further increased.

Confronted with the same problem, Sharma (1973) argued that the observed differences in organic matter are apparently too small to offset the deleterious effects of exchangeable sodium on soil structure and on toxicity for the other plants species. However he concludes that it may be difficult to assess the exact contribution of plant-induced soil variability because of complications caused by simultaneous variations in several micro-environmental factors.

To make a balance, the implications of both aspects should be explored, and possibly other soil properties should also be assessed. Sharma (1973) extended the analysis to other physico-chemical properties (water penetration and storage, structural stability, hydraulic conductivity, and water retention), to obtain a more comprehensive appraisal of the changes induced by *A. nummularia*. He reports a reduction of aggregate stability and of drainage conditions under the plants, for the surface layer (0–7.5 cm).

Table 4
Av. values for under canopy (Uc) and between plants (Bp) samples. The analysis on all samples (column 1 and 2) was done by a paired samples *t* test based on the average values for the three Uc and the three Bp samples in each plot, for each layer (nine values, one per plot, for both layers A and B). The analysis on G and M samples (column 3 and 4) was done by an unpaired *t* test based on all samples, per each layer. Differences marked by a * are statistically significant ($\alpha = 0.05$). ΔpH = H_2O–KCl. G = Good; M = moderate; P = poor; A = 0–10 cm layer; B = 10–20 cm layer.

		1. All samples, A layer			2. All samples, B layer			3. G + M plots samples, A layer			4. G + M plots samples, B layer		
Variable	Unit	av. Bp	av. Uc	% differ.	av. Bp	av. Uc	% differ.	av. Bp	av. Uc	% differ.	av. Bp	av. Uc	% differ.
OC	%	0.63	0.48	32.2*	0.45	0.48	−6.0	0.51	0.71	40.2*	0.53	0.48	−9.1
N	%	0.13	0.12	9.0*	0.12	0.12	−0.2	0.12	0.14	11.2	0.12	0.12	−1.4
pH H_2O		8.10	7.96	1.9*	8.31	7.97	4.2*	8.09	8.20	1.4	8.07	8.51	5.5*
pH KCl		7.73	7.67	0.7	7.62	7.57	0.6	7.79	7.85	0.8	7.75	7.92	2.3
ΔpH		0.38	0.28	34.1	0.69	0.40	72.7*	0.31	0.35	14.9	0.32	0.58	82.9*
Carb	%	7.90	8.40	−6.0	9.46	10.01	−5.5	9.39	8.23	−12.4	9.80	7.59	−22.5
ECse	(dS m^{-1})	4.534	4.075	11.3	2.618	5.839	−55.2	4.661	6.049	29.8	8.131	3.222	−60.4*
$[Na^+]$tot	(meq 100 g^{-1})	1.509	1.028	46.8*	0.974	1.212	−19.7	1.280	1.849	44.5	1.750	1.190	−32.0
$[Na^+]$se	(meq 100 g^{-1})	0.450	0.282	59.6	0.256	0.346	−25.9	0.338	0.573	69.6	0.485	0.287	−40.8
$[K^+]$tot	(meq 100 g^{-1})	2.573	2.647	−2.8	1.921	1.716	11.9	3.224	2.469	−23.4	1.836	2.333	27.1
$[K^+]$se	(meq 100 g^{-1})	0.049	0.015	217.6*	0.014	0.012	19.0	0.020	0.070	255.3*	0.017	0.019	13.3
$[Mg^{2+}]$tot	(meq 100 g^{-1})	1.056	1.089	−3.1	1.114	1.107	0.6	1.130	1.124	−0.5	1.192	1.113	−6.6
$[Mg^{2+}]$se	(meq 100 g^{-1})	0.015	0.018	−19.9	0.011	0.030	−62.7	0.018	0.019	7.4	0.041	0.014	−66.1
$[Ca^{2+}]$tot	(meq 100 g^{-1})	12.818	14.822	−13.5	15.085	16.807	−10.2	16.316	11.716	−28.2	16.864	13.248	−21.4
$[Ca^{2+}]$se	(meq 100 g^{-1})	0.068	0.116	−41.2	0.067	0.168	−60.2	0.137	0.084	−38.6	0.261	0.074	−71.7*
CEC	(meq 100 g^{-1})	14.967	12.547	19.3*	13.847	14.722	−5.9	12.809	15.203	18.7	14.557	15.028	3.2
SAR		2.303	0.965	138.7*	1.874	1.030	81.9	1.157	2.634	127.7*	1.169	2.157	84.5
ESP	%	8.459	7.245	16.8	5.145	6.861	−25.0	9.399	10.094	7.4	10.312	6.053	−41.3

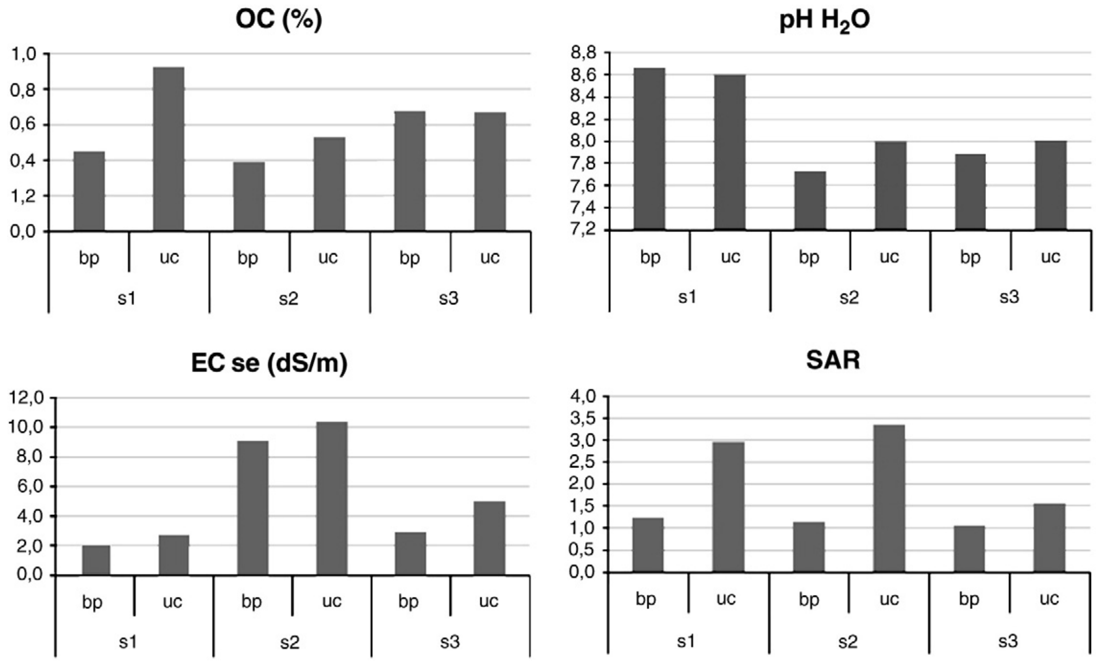

Fig. 3. The average Uc (under canopy) and Bp (between plants) values in the A layer (0–10 cm), considering all the G and M plot samples in each of the three sites (s1, s2, s3), for four variables (pH H_2O, OC, EC_{se} , SAR). Degree of plant development: G = good; M = moderate.

Cepeda-Pizarro et al. (1992) observed lower micro-arthropods numbers under *A. nummularia* compared to autochthonous plant species. Conversely, Maganhotto de Souza Silva et al. (2008) found that soils cultivated with *A. nummularia* and irrigated with saline effluents, in semi-arid conditions in Brazil (annual rainfall ranging between 400 and 600 mm), improved their fertility (organic carbon, nitrogen and phosphorus contents) and microbiological properties (enzymes activity). The effects on plant biodiversity and plant stress induced by the increased sodium level were just mentioned by Sharma (1973), but not assessed.

The few available studies are not easily comparable, because they refer to different climate, soil and management conditions. A balance with regard to soil quality change should be preferably made case by case, considering the local conditions.

5. Conclusions

The evaluation of land restoration interventions is a complex exercise, involving technical, economical, social, and ecological considerations (DSD, 2009; Zucca et al., 2009). Previous studies highlighted that the investigated plantations were considered as successful in terms of available fodder biomass, landscape change, and social acceptance (Zucca et al., 2011). The socio-economic benefits have been acknowledged by the local communities, as the plants were appreciated for their easy establishment and their contribution to the livestock feeding.

The present work focuses on the effects of the plantations on the soils. These are mostly due to the plant litter incorporation, to the root uptake, to the shadowing action of plants, to the changes in flora and in fauna activity, and to grazing. Plant litter (leaves and flowers) plays a major role on salinity and organic matter, but the latter, as well as soil structure, is also influenced by the other factors mentioned above, especially by grazing.

In the Ouled Dlim case the observed OC increase in the topsoil is higher than in previous studies, even though the climate is dryer. However, the sustainability in the long term is in doubt due to sodium accumulation in the topsoil. Once the immediate goals of mitigating desertification and rural abandonment have been achieved, a suitable strategy should be implemented to promote the evolution of the present artificial sylvo-pastoral system toward a more natural and sustainable one.

Further, systematic research and monitoring would be needed to fully understand the relationships linking the variables at play. Nevertheless, the results obtained in the study area can constitute a concrete input to the local administrators on the environmental benefits obtained through the restoration intervention, and to start a discussion about the future land use strategies.

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