Impact of agricultural management on salts accumulation in dryland soils of central Tunisia

Andrea Salvucci,[1] Dominique Serrani,[1] Alberto Agnelli,[2,3] Valeria Cardelli,[1] Lorenzo Camponi,[1] Giuseppe Corti,[1,4] Stefania Cocco[1]

[1]Department of Agriculture, Food and Environmental Sciences, Polytechnic University of Marche, Ancona; [2]Department of Agricultural, Food and Environmental Sciences, University of Perugia; [3]Research Institute on Terrestrial Ecosystems (IRET), National Research Council (CNR), Sesto Fiorentino (FI); [4]Research Centre for Agriculture and Environment, CREA – Council for Agricultural Research and Economics, Firenze, Italy

Highlights

- *Irrigation by submersion leached salts down to deep soil horizons that are less colonized by roots.*
- *The presence of soil cover fostered the reduction of water evaporation and capillary rise of salts.*
- *Unsuitable agricultural management and/or misuse of water may compromise soil conservation.*

Abstract

Drylands represent about one-third of the global land and mainly occur in Africa and Asia. Because of the arid conditions, dryland soils are characterized by salt accumulation. Although salt-affected soils are unsuitable for agriculture, some arid lands have been cultivated for a long time. However, especially in the last decades, because of the increasingly warmer climatic conditions and human migration toward favorable environments, a progressive abandonment and degradation of drylands has occurred. Therefore, it is necessary to assess the effects of cultivation on saline soils to develop appropriate soil management techniques to ensure their fertility. This work aims to evaluate the evolution of salinization from currently cultivated soils to soils that have been abandoned for different lengths of time in arid areas of central Tunisia. Morphological and physicochemical properties of the studied soils indicated that the cultivation, through irrigation and the presence of soil cover, reduced salt accumulation in the upper soil horizons. Salt leaching towards deeper horizons and depressed evaporation, which reduced capillary rising, maintained electrical conductivity within tolerable values for most crops. Conversely, the abandonment of previously cultivated fields compromised soil fertility, threatening soil conservation and stabilization of agricultural production in the medium to long term.

Correspondence: Dominique Serrani, Department of Agriculture, Food and Environmental Sciences, Polytechnic University of Marche, Via Brecce Bianche 10, 60131 Ancona (AN), Italy.
E-mail: d.serrani@staff.univpm.it

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Introduction

Drylands cover one-third of the global land area, about 52 million km^2, mainly located in Africa and Asia (Hannachi *et al.*, 2015). They are considered one of the most susceptible and fragile ecosystems, vulnerable to degradation and land-use change, water shortage, drought, and desertification (FAO, 2019). Due to the dry conditions, these lands are also characterized by a massive accumulation of salt, which interferes with plant (crop) growth (Canfora *et al.*, 2017). On a global scale, Negacz *et al.* (2022) have estimated a global surface of 16.646 million km^2 of salt-affected soils with an electrical conductivity greater than 4 dS m^{-1}. However, arid and semi-arid regions have been cultivated for a long time using various agronomic systems, conservative in some cases and degradative in others (Plaza-Bonilla *et al.*, 2015; Luján Soto *et al.*, 2021). In arid and semi-arid regions, soil degradation has often exacerbated wind erosion and nutrient loss (Duniway *et al.*, 2019; Oduor *et al.*, 2022), or led to water scarcity and further accumulation of secondary salts (Devkota *et al.*, 2022). Salts accumulation may be due to natural causes (primary salinization) or human-induced processes, defined as secondary salinization (Tomaz *et al.*, 2020). Natural salinization is the consequence of an accumulation of salts released by mineral weathering (Mazhar *et al.*, 2022). In contrast, secondary salinization is caused by human activities, such as irrigation with brackish or saline water, lack of drainage (Wang *et al.*, 2022), and intrusion of seawater promoted by groundwater overexploitation in coastal areas (Vittori Antisari et al., 2020). Where salinization and even warmer climatic conditions occur, rural populations are forced to migrate toward more favorable environments, causing gradual land abandonment and socioeconomic instability in those areas (Stringer *et al*., 2021). To guarantee soil conservation and stabilization of crop production, it is therefore fundamental to investigate soil status and properties to understand in detail the processes of salinization and develop the most suitable soil managing techniques to ensure soil fertility settings (Schwilch *et al.*, 2014).

Within the Mediterranean basin, Tunisia is one of the North African countries exposed to soil aridity, salinity, and water scarcity (Ben Mhenni *et al*., 2021), with 98.5% of the area occupied by drylands (Prăvălie, 2016), and 10% of the land affected by salinization (Zarai *et al*., 2022). To assess the most sustainable land management of the arid and semi-arid Tunisian regions, various studies were performed: *e.g.*, i) Corti *et al*. (2020) investigated the geomorphological and pedological processes in pre-desert soils; ii) Hannachi *et al*. (2015) studied the chemical and biochemical properties of cultivated soils under different managements; iii) Tambone *et al*. (2022) examined the role of *Tamarix aphylla* L. (Karst.) in the degradation and evolution of the soil organic matter; iv) Bani *et al*. (2021) determined the effectiveness of different crop rotations with respect to soil salinity. Nonetheless, despite other studies addressing the issue of Tunisian dry and saline soils (*e.g.*, Bouksila *et al*., 2013; Del Barrio *et al.*, 2016; Ibrahimi *et al*., 2022; Slimane *et al.*, 2022), little attention has been paid to the changes of soil conditions after the abandonment of cultivated fields. To fill this gap, the main objective of this work was to assess the extent of salinization in currently cultivated soils and in soils abandoned for different lengths of time (15, 30, and 55 years) in an arid area of central Tunisia.

Materials and Methods

Study sites

The study sites are in the coastal oasis of Chenini Nahel and in the continental oasis of Metouia, both located nearby the Gulf of Gabès, Central Tunisia (Figure 1). The climate is arid Mediterranean, characterized by a mean annual precipitation of 152 mm and a mean annual air temperature of >20°C (Climate-data, 2022). According to Hannachi *et al.* (2015), the Aridity Index is 0.12, corresponding to an arid type of dryness (UNEP, 1997).

The parent material consists of cretaceous limestone, and the soils are mostly made of gypsiferous sand with halite and surmounted by gypsum crusts (Kouki and Bouhaouach, 2009). The salinization of the area is generally due to the shallow saline to brackish groundwater, which ranges in depth from 1.3 to 1.5 m (Ibrahimi *et al*., 2010; Boulbaba *et al*., 2012). Four areas were selected to investigate the effect of different land management over the years (Figure 1): i) cultivated soil (CS), which had been cultivated for nine years with henna (*Lawsonia inermis* L.), watered by submersion (≈400 mm ha^{-1} y^{-1}), and amended with 10 Mg ha^{-1} y^{-1} of dry wastes of various vegetal and animal residues composted with manure. The area was characterized by a "multilayer cropping system" consisting of date palms (*Phoenix dactylifera* L.) as the dominant layer at the periphery, pomegranate (*Punica granatum* L.), and olive trees (*Olea europaea* L.) as the middle level under date palms, and henna (*Lawsonia inermis* L.) as the lower layer, in which the trench was opened; ii) non-cultivated soil for 15 years (NS15) that, after abandonment, has been superficially plowed every 4-5 years to reduce cane invasion; iii) soil abandoned at least 30 years (NS30); iv) soil

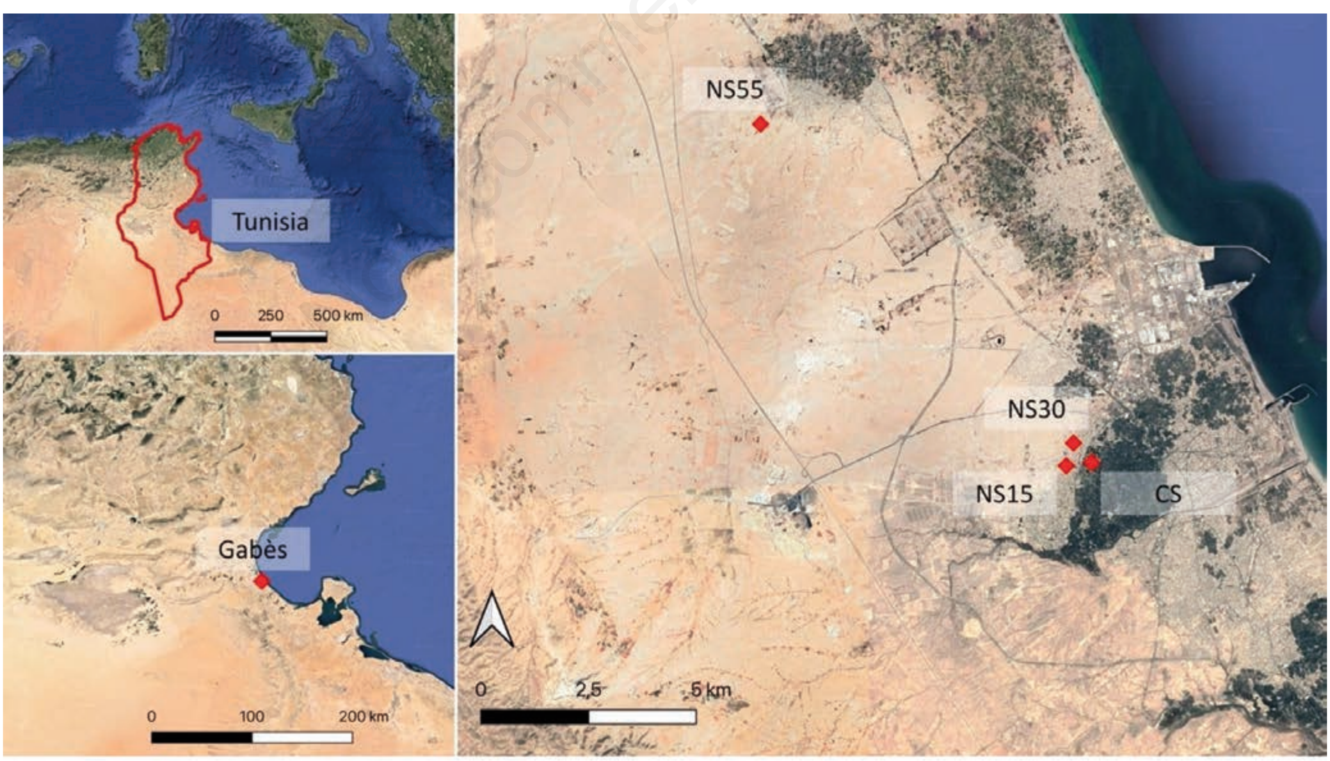

Figure 1. Schematic map and location of the study sites in the oases of the Governorate de Gabès (central Tunisia). Dots represent the cultivated soil (CS), the non-cultivated soil from 15 years (NS15), the non-cultivated soil from 30 years (NS30), and the non-cultivated soil from 55 years (NS55).

abandoned at least 55 years (NS55). Abandoned soils were previously managed with a similar agroforestry system made of date palm, fruit trees [olive tree, pomegranate, and grapevine (*Vitis* sp.)], herbaceous crops (*Panicum miliaceum* L., *Medicago sativa* L.) and other vegetables, and watered by submersion.

Soil sampling and analyses

In early autumn, a survey with the opening of auger holes and mini pits was conducted to assess soil spatial variability and select a representative study site per each area. In each study site, a large trench (from 1.5 to 2 m in width) was dug, and the soil profile was morphologically described as per Schoeneberger *et al.* (2012). Soil samples were collected in double according to genetic horizons at the extremes of the trench. The singular components forming the BCyy and Bty horizons of NS15 (Table 1) were described separately but sampled together. Once in the laboratory, the samples were air-dried and sieved at 2 mm to remove skeletal fragments.

Particle-size distribution was determined via the pipette method (Day, 1965). The mineralogical composition was determined by x-ray diffraction with a Philips PW 1830 diffractometer (Philips, Eindhoven, Netherlands), using the Fe-filtered Co Ka1 radiation and operating at 35 kV and 25 mA; the step size was 0.02°2q and the scanning speed was 1 second per step. A semi-quantitative estimation was obtained after the identification of the minerals based on their characteristic peaks (Brindley and Brown, 1980; Dixon and Schulze, 2002). The abundance of each mineral was estimated from the surface area of the respective primary peak by multiplying the peak height by the width at the peak half-height (Cocco *et al.*, 2015). The following analyses were run on the saturated paste extracts obtained following Richards (1954). The pH was determined potentiometrically, and the electrical conductivity (EC) was measured by a conductivity meter (CO3100L, VWR, USA). Soluble cations (calcium, magnesium, potassium, sodium, aluminum, manganese, barium, zinc, nickel, copper, strontium, and lead) and anions (fluoride, chloride, nitrate, and sulphate) were determined using inductively coupled plasma-optical emission spectrometry (ICP-OES Optima 8300, Perkin Elmer, USA). Exchangeable sodium percentage values were calculated from the sodium adsorption ratio following the model proposed by Seilsepour (2009).

Data analysis

The mineralogical composition was determined on one set of soil samples only; hence, no statistical treatment was run. Instead, for each sample collected, a single determination was performed for particle-size distribution, pH, and EC, while two extractions per sample were obtained for the soluble cations and anions and averaged to obtain more reliable results. The results of the two samples per horizon collected in each trench were considered replicates, and the results of each sample were used to calculate the average and the standard deviation. Multivariate analysis was performed in R software (version 4.0.3) for dataset interpretation. Principal component analysis (PCA) was carried out [FactoMiner R package] to identify parameters that discriminated the land management. Thus, the boxplot has been performed [ggplot2 package] to compare parameters among study sites: the line inside each box represents the median, the bottom and the top of the box are the twenty-fifth and seventy-fifth percentile, and the upper and lower whiskers indicate the minimum and maximum values. A lack of overlapping among box plots indicates a statistically significant difference (Wild *et al.*, 2011; Krzywinski and Altman, 2014). Conversely, to compare the partially overlapped box plots, the Distance Between Medians (DBM) and the Overall Visible Spread (OVS) were used according to Wild *et al.* (2011): boxes with a DBM/OVS ratio greater than 0.33 were considered significantly different. Ba, Ni, Pb, F, and NO_3 were not included in the statistical analysis because most of the values were under the limit of detection.

Results

In all the areas, soils belonged to the order of Aridisols because of the acidic soil moisture regime (Van Wambeke, 1982) and the presence of an ochric epipedon with high color value and chroma (Soil Survey Staff, 2014). The study areas differed in soil cover percentage, which was 100% in CS because of the cultivation with henna but ranged from 20% in NS15 to 90-100% in NS30 and NS55 (Table 1). The surface of all the soils showed thin saline crusts that, when observed under a lens, appeared dominated by gypsum, with little halite in CS and NS15. The sub-superficial horizons presented features due to gypsum accumulation (suffix y, Table 1) in the first 40-50 cm of depth in CS and NS15; instead, the deeper horizons of these soils and almost all the horizons of NS30 and NS55 were dominated by gypsum (suffix yy, Table 1). The NS15 soil had illuvial morphologies made of a lamella and a Bt horizon crossed by 2-3 mm thick gypsum veins. Even though Soil Survey Staff (2014) recommends the use of lamella when it "has more silicate clay than the overlying eluvial horizon", we used this qualifier to stress the formation of a thin horizon characterized by illuvial silt. Soil structure was similar in all the soils, with very friable angular and/or subangular blocks, except for BCyy4 and Cyy horizons of NS55, which were structureless. The mineralogical composition confirmed the dominance of gypsum in all the soils, with quartz that mainly dominated the superficial horizons (*Supplementary material S1-S4*). Small amounts of calcite, plagioclases, and dolomite were also present, while halite, amphiboles, and clay minerals were absent or present in traces.

The 1st principal component (PC1) and the 2nd principal component (PC2) of the PCA explained a cumulative percentage of the variance amounting to 71%, indicating the samples grouped for homogeneous variables and the variables involved in the clustering (Figure 2).

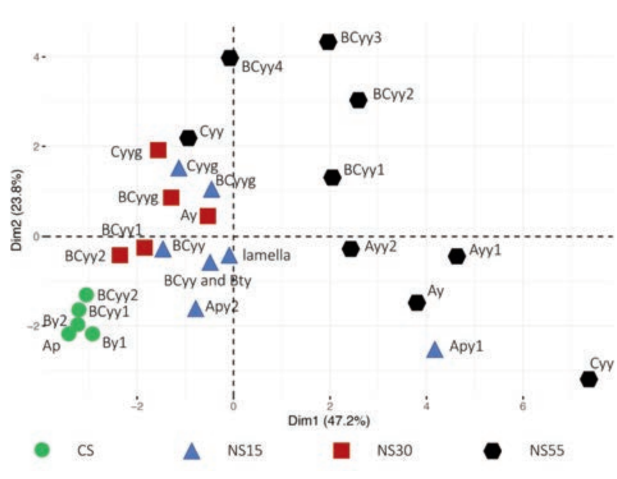

Figure 2. Results of principal component analysis (PCA) of the horizons properties from the cultivated soil (CS), the non-cultivated soil for 15 years (NS15), the non-cultivated soil for 30 years (NS30), and the non-cultivated soil for 55 years (NS55) of the oases of the Governorate de Gabès (central Tunisia).

Table 1. Morphological descriptions of soil profiles opened at Chenini Nahel and Metouia, Governorate de Gabès, (central Tunisia). Codes according to Schoeneberger et al. (2012).

Horizon	Singular components	Depth cm	Texture[a]	Colour[b]	Structure[c]	Consistence[d]	Roots[e]	Skeleton[f]	Boundary[g]	Observations[h]
CHENINI NAHEL (33°53' N; 10°04' E) Altitude: 22 m; distance from the sea: 4.5 km										
CS - Soil cultivated with henna (*Lawsonia inermis* L.); irrigated by submersion (≈400 mm of water per hectare per year). Slope: ≈0%; soil cover: 100% due to henna; drainage class: well-drained. Soil: sandy, gypsic, thermic, Leptic Haplogypsid (Soil Survey Staff, 2014)										
Ap		0-10	s	10YR 6/3	2m, c abk-sbk	m(vfr), (w)ss	3vf, f	sc	CS	whitish SC (gypsum and halite); CH; SF
By1		10-27	s	10YR 6/4	2f, m, c sbk	m(vfr), (w)ss	3vf, f, m, c	sc	CW	CH; SF
By2		27-51	s	10YR 6/4	2m, c abk-sbk	m(vfr), (w)ss	3vf, f, m, c	sc	CW	CH
BCyy1		51-72	s	10YR 7/6	1m, c abk	m(vfr), (w)ss	1vf, f; 2m, c	0	CS	few MNC
BCyy2		72-123+	s	10YR 7/6	1f, m, c abk	m(vfr), (w)ss	1vf, f; 1-2m, c	0	-	few MNC
NS15 - Soil non-cultivated for 15 years but superficially ploughed every 4-5 years. Slope: ≈0%; soil cover: ≈20% mostly due to cane [Phragmites australis (Cav.) Trin. ex Steud], with sparse tamarisk (*Tamarix* sp.); drainage class: well-drained. Soil: sandy, gypsic, thermic, Typic Haplogypsid (Soil Survey Staff, 2014)										
Apy1		0-17	ls	10YR 6/4	2m, c sbk & f, m gr & sg	m(vfr), (w)ss	2m, c	0	CW	whitish SC (gypsum and halite)
Apy2		17-37	s	10YR 5/4	3tn, m pl	m(vfr), (w)ss	1vf, f, m, c	0	CW	SF; "salt and pepper" effect
lamella		37-39	s	10YR 6/4	1m, c abk	m(vfr), (w)ss	2vf, f	0	CS	
BCyy and Bty	BCy'	39-53	s	10YR 6/4	1m, c abk	m(vfr), (w)ss	2vf, f	0	CS	few MNC
	lamella	53-55	ls	10YR 5/2	1m, c abk	m(vfr), (w)ss	2vf, f	0	CS	2-3 mm GYV
	BCyy"	55-64	ls	10YR 6/2	1m, c abk	m(vfr), (w)ss	2vf, f	0	CS	
	Bty	64-68	sl	10YR 6/3	1m, c abk	m(vfr), (w)ss	2vf, f	0	CS	2-3 mm GYV
BCyy		68-110	ls	10YR 6/4	1m, c abk	m(vfr), (w)ss	1vf, f; 3m, c	sc	CS	few MNC; light mottling
BCyyg		110-120	sl	10YR 6/4	1c abk	m(vfr), (w)ss	1vf, f; 2m, c	sc	CS	
Cyyg		120-125+	ls	10YR 6/3	1m, c abk-sbk & 1tn pl	m(vfr), (w)ss	1vf, f, m, c	sc	-	diffuse MNC; light mottling
NS30 - Soil non-cultivated for 30 years. Slope: ≈0%; soil cover: ≈100% mostly due to cane [*Phragmites australis* (Cav.) Trin. ex Steud] (70%) and tamarisk (Tamarix sp.) (30%); drainage class: well-drained. Soil: sandy, gypsic, thermic, Leptic Haplogypsid (Soil Survey Staff, 2014)										
Ay		0-9	ls	10YR 7/4	2m,c abk-sbk	m(vfr), (w)ss	2vf	sc	CW	yellowish SC (mostly gypsum, few halite)
BCyy1		set-38	s	10YR 6/3	1'm,c abk	m(vfr), (w)ss	1vf, f; 3m, c	sc	CW	1 mm GYV
BCyy2		38-66	s	10YR 6/4	1'm,c abk	m(vfr), (w)ss	1vf, f; 3m, c	sc	CW	few MNC; light mottling, GYC
BCyyg		66-75	ls	10YR 6/4	1c abk	m(vfr), (w)ss	1vf, f; 2m, c	sc	CS	few GYC
Cyyg		75-85+	ls	10YR 6/3	1'm,c abk-sbk, tn pl	m(vfr), (w)ss	1vf, f, m, c	sc	-	diffuse MNC, light mottling
METOUIA (33°57' N; 09°59' E) Altitude: 44 m; distance from the sea: 7.5 km										
NS55 - Non-cultivated soil for 55 years. Slope: ≈0%; soil cover: ≈90% mostly due to *Atriplex* sp.; drainage class: well-drained. Soil: coarse-loamy, gypsic, thermic, Leptic Haplogypsid (Soil Survey Staff, 2014)										
Cyy		0-2	scl	7.5YR 5/4	-	-	0	0	AS	yellowish SC (mostly gypsum, few halite); CH
Ay		02-ago	sl	7.5YR 6/4	1f, m, c abk-sbk	m(vfr), (w)ss	1m; 2vf, f	0	CS	CH
Ayy1		ago-15	ls	7.5YR 6/6	1f, m abk-sbk	m(vfr), (w)ss	1m; 2vf, f	0	CW	friable GYN; 1 cm GYC; CH
Ayy2		15-22	ls	7.5YR 6/4	2f, m, c abk	m(vfr), (w)ss	1f, m; 2vf	0	CW	ORM; GYN; CH
BCyy1		22-34	sl	7.5YR 6/6	1f, m, c abk	m(vfr), (w)ss	1vf, f	0	CS	ORM
BCyy2		34-50	ls	7.5YR 5/4	1f, m, c abk	m(vfr), (w)ss	1vf, f	0	CS	GYC; SF
BCyy3		50-71	sl	7.5YR 6/4	1f, m, c abk-sbk	m(vfr), (w)ss	1vf, f	0	CS	GYC
BCyy4		71-95	sl	7.5YR 6/4	m	m(vfr), (w)ss	0	0	CS	7-8 mm GYN; 1 mm vertical GYV
Cyy		95-109+	ls	7.5YR 6/6	m	m(vfr), (w)ss	0	0	-	3-4 mm GYN; partial gypsum cementation

[a]s=sand, ls=loamy sand, sl= sandy loam, scl=sandy clay loam; [b]According to the Munsell Soil Color Chart (1992 edition); [c]1=weak, 2=moderate, 3=strong; f=fine, m=medium, co=coarse, tn=thin; gr=granular, abk=angular block, sbk=subangular block, pl=platy, sg=single grain, m=massive; [d]m=moist; vfr=very friable; (w)ss=slightly sticky; [e]0=absent, 1=few, 2=common, 3=many; vf=very fine, f=fine, m=medium, c=coarse; [f]By sight; 0=absent, sc=scarce; [g]C=clear; S=smooth, W=wavy; [h]SC=salty crust; MNC=manganese concretions; GYV=gypsum veins; GYC=gypsum concretions; GYN=gypsum nodules; CH=charcoal fragments; SF=shell fragments; ORM=organic materials.

Table 2 shows the eigenvectors of variables for the selected dimensions. In the PCA, horizons belonging to the NS55 soil and the Apy1 horizons of the NS15 soil are separated from the others mainly in the PC1, and the discriminating drivers were represented by EC, Mg, K, Na, Cl, and SO_4 measured on the extract of saturated paste.

The physicochemical parameters and the results of univariate analysis (*Supplementary material S5-S9*). Most of the parameters (17 out of 22) displayed significant differences among the investigated soils. Of those, the discriminating parameters in PCA (PC1) groups have been reported in the form of boxplots (Figure 3), showing the highest and the lowest values in NS55 and CS, respectively, and displaying the sequence NS55 > NS15 > NS30 > CS.

Discussion

The formation of the salty crust observed at the surface of all the investigated soils was ascribed to the accumulation of salts due to the evaporation of the soil solution summoned at the surface by capillary rising (Mollema *et al*., 2012; Ferronato *et al*., 2016). As proof of this, EC values were slightly higher (CS) or much higher (NS15, NS30, NS55) than 4 dS m^{-1}, which is the threshold identified for saline soils (Richards, 1954; Tomaz *et al*., 2020), following the sequence NS55 > NS15 > NS30 > CS (Figure 3). The lowest EC values of CS (from 3.86 to 5.21 dS m^{-1}) were attributed to the ongoing irrigation by submersion, which promoted salt leaching down to the deep horizons (Qadir and Murtaza, 2001). Once salts have been removed from the soil portion interested by roots (the upper 50 cm of soil, represented by Ap, By1, and By2 horizons), crop development is favored and the improved soil cover reduces evaporation and capillary rising, maintaining EC of the upper horizons within limits tolerated by plants (Bernstein, 1975; Liu *et al*., 2019; Zhang *et al*., 2022).

Table 2. Eigenvectors of variables for selected dimensions (1st principal component and 2nd principal component) of the parameters measured in differently managed soils from Chenini Nahel and Metouia, Governorate de Gabès, (central Tunisia).

	PC1	PC2
Sand	-0.70162	-0.39454
Silt	0.44648	0.55230
Clay	0.71791	0.08621
pH	0.68421	0.21922
Electrical conductivity	0.94268	-0.30440
Ca	-0.34441	0.87144
Mg	0.93057	-0.06057
K	0.93483	-0.22121
Na	0.97591	-0.04969
Sr	0.37277	0.79409
Al	0.51888	0.48671
Cu	0.11480	-0.62401
Mn	0.11740	0.52976
Zn	0.07256	0.85340
Cl	0.96195	-0.17576
SO_4	0.90001	-0.29835

PC1, 1st principal component; PC2, 2nd principal component.

In the NS15, the presence of a lamella between Apy and Bcyy horizons, and a Bcyy horizon interrupted by lamellae between 53 and 54 cm and containing a Bt horizon, represented an indication of the past agricultural management consisting of soil tillage and intense watering that favored the translocation of fine particles (Warrington *et al*., 2007; Sauzet *et al*., 2016). Since the soils of all the study sites showed a coarse texture (loamy sand to sandy loam), high volumes of water are required to induce translocation and accumulation of salts (mostly gypsum) and fine particles (which originated the Bt horizon) from the superficial to the deep horizons (Presley *et al*., 2004; Warrington *et al*., 2007), so as to form lamellae. Considering that in CS, irrigation equivalent to ≈400 mm ha^{-1} y^{-1} and ongoing agricultural practices have produced only signs of slight gypsum translocation without the formation of lamellae, gypsum veins, or Bt horizons, we deduced that NS15, when cultivated, should have received more irrigation water and/or was irrigated for a longer time than CS. Further, as reported by Ibrahimi *et al*. (2022), the interruption of agricultural practices and the abandonment of areas previously cultivated could have enhanced the evaporation rate and the rising of salts along the soil profile by capillary flow. Then, salt accumulation at the surface (Table 1) would have favored the gradual colonization of sparse pioneer and halophyte species (He *et al*., 2014). In NS15, the lack of watering (coupled with the sporadic tillage) and the sparse nat-

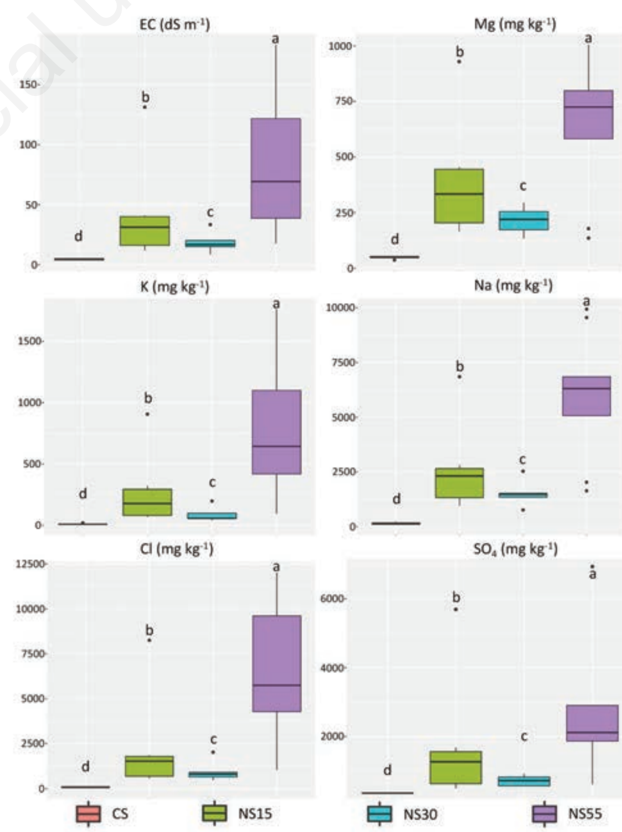

Figure 3. Boxplots representing properties for the cultivated soil (CS), the non-cultivated soil for 15 years (NS15), the non-cultivated soil for 30 years (NS30), and the non-cultivated soil for 55 years (NS55) of the oases of the Governorate de Gabès (central Tunisia). Different letters have been assigned to boxes with a Distance Between Medians/Overall Visible Spread ratio >0.33.

ural revegetation limited the translocation of salts down the profile, maintaining a high level of EC (Barnard *et al*., 2010; He *et al*., 2014). Conversely, the lack of cultivation and soil tillage in NS30 favored cane [*Phragmites australis* (Cav.) Trin. Ex Steud] and tamarisk (*Tamarix* sp.) colonization, which guaranteed soil shading and protection from high temperatures, with subsequently lower capillary rising, salt accumulation at the surface, and EC values than NS15. In extreme conditions like those of NS55 (Figure 3, Table S9 of Supplementary Materials), which had the highest EC values and salt concentration (Mg, K, Na, Cl, SO_4 ions), a progressive change in vegetal composition and reduction of soil cover occurred. Since the pedological and climatic conditions were similar to those of other soils, it is possible that time was key. In fact, although 30 years after abandonment the rate of salt rising and accumulation at the soil surface was less than in NS15, in the following 25 years there was a gradual increase of salt concentration at the surface, a vegetation change (Burdick *et al*., 2001; Glenn *et al*., 2012), a reduction of the canopy cover, an increase of evapotranspiration and, therefore, the rising of salt-rich solutions causing accumulation of salts at the soil surface (He *et al*., 2014).

In summary, the mechanisms involved in the progressive soil salinization after the abandonment of cultivation seemed to reach a first step of plant cover with a consequent reduction of capillary rising and great salinization within two-three decades, to evolve toward a strong phase of salinization in the following two decades. At this second phase of evolution, soil can be considered deeply compromised for agricultural purposes.

Conclusions

Drylands represent unfavorable environments for agricultural purposes because of aridity and salt accumulation. The disjointed distribution of salt accumulation in relation to the increased period of non-cultivation suggested the impossibility of generalizing the process of soil salinization and highlighted the strong impact exerted by agricultural practices and vegetation dynamics. The interruption of land management and the abandonment of the area strongly compromised soil conservation and agricultural production in the long term, though dense natural vegetation cover may reduce the soil evaporation rate and capillary rising of salts within the first phase of evolution. In view of this, applying suitable land management, such as ongoing adequate water uses, is mandatory to promote salt leaching down to the deepest soil portions, while maintaining the electrical conductivity at tolerable levels for crops within the rooting depth. Therefore, the more harmonized the agricultural practices are with pedoclimatic conditions, the greater soil fertility preservation and stabilization of crop production.

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