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Typology characterisation and monitoring of arid soils in an agroecosystem environment: Case of Ziban oasis, Algeria

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Abstract: This study addresses date palm growth and Saharan agriculture's substantial environmental changes in Ziban agroecosystems (ZAE). Arid climate and vulnerable soils make oasis environments fragile. Most soils are sandy and rich in saline accumulations. This study characterised ZAE dry soils, determined its typology using the World Reference Base for Soil Resources (WRB) classification and US soil taxonomy (ST), and assessed their degradation using remote sensing (RS). Fieldwork identified representative oasis based on gypsum, calcareous crusts, and salinity. Ten soil profiles were selected using two topo-sequences, and 27 samples were obtained at 0–30, 30–60, and 60–120 cm. Analyses were carried out on organic matter (OM), pH, electrical conductivity (diluted extract 1:5), $CaCO_3$, gypsum, and soil texture. Oasis soils are dominated by gypsum and are all affected by salinity. The rates of OM and $CaCO_3$ are low to moderate. The land use and degraded areas were identified using RS data, field research, and soil analytical results. Soil classification revealed variability in soil diversity. The Typic and Gypsic Haplosalids' ST soil group (SG) and the WRB Reference Soil Group (RSG) of Gypsic Solonchaks (Hypersalic) and Yermic Gypsic Solonchaks are equivalent. The Typic Haplogypsids and Typic Petrogypsids (ST) correspond to the Gypsisols (WRB). The Typic Torripsamments (ST) are correlated with the Arenosls (WRB). Differentiating degraded areas according to their degree of degradation and specific soil features is made possible by characterising the soils and identifying their typology. Farmers must use the right management strategies for each situation to sustain the oasis agroecosystem.

Keywords: agroecosystem, date palm, remote sensing, soil classification, soil degradation, soil taxonomy, World Reference Base

INTRODUCTION

The demand for natural resources is rising dramatically due to population growth. The greatest challenge to providing food and nutritional security is the demand for higher-quality food. The populations of low-income countries are particularly at risk because of extremely high soil degradation (Naorem *et al.*, 2023).

Soil is essential in supporting healthy ecosystem sand providing products and services (Keesstra *et al.*, 2016; Lorenz, Lal and Ehlers, 2019). As a result, soils play a crucial role in fulfilling the UN's sustainable development goals. Drylands cover more than 40% of the Earth's surface, and due to predicted increases in aridity caused by climate change, their global expanse and socio-ecological implications are expected to grow (Moreno-Jiménez *et al.*, 2019). Dryland areas are habitat to more than a third of the world's population (Prăvălie, 2016; Mortimore *et al.*, 2022). They are defined as regions with an aridity index (*AI*) of <0.65 (mean annual precipitation/mean annual potential evapotranspiration) (Cherlet *et al.* (eds.), 2018). With 37% of the world's dry zones and 66% of its land area classified as either desert or arid, Africa has been facing significant risk from land degradation and desertification (Naorem *et al.*, 2023). Soil salinity is a major factor in declining productivity in agriculture and presents an important challenge to our ability to feed the world's growing population (Kopittke *et al.*, 2019).

Since its initial publication in 1975, soil taxonomy (ST) has undergone significant change, particularly within the Aridisol order (Yaalon, 1995). Many of the criteria used to classify Aridisols today come from the western North American deserts, which cover a wide range of latitudes, temperatures, and moisture (Finstad, Pfeiffer and Amundson, 2014); a fact that suggests that more research is needed. In addition, the number of papers published and indexed in Scopus between 1975 and 2014 focusing on topics like "soil types" and "soil classification" (18,265), shows that Aridisols are understudied (Hartemink, 2015). Indeed, scientific literature shows that during these 40 years, the interest in Aridisols has increased, but the articles published on the typology and classification of these soils (117) represent only 0.64% during this period.

The arid region of the Ziban has been subject to much soil-related data collection. However, soil taxonomy and mapping research is limited, particularly in the last 30 years. The Ziban region of Algeria had previously undergone soil surveys at various scales, ranging from 1:500,000 to detailed scales (Ramdane, 2001). Since then, significant research has been carried out on the soils of Algeria's arid regions, such as the work by Pouget (1980), Dubost (1986), Halitim and Robert (1987), Halitim (1988), Nedjimi (2012), and Hannachi *et al.* (2015). The Ziban oasis environment (ZOE) is degrading in many ways, as stated by Aidaoui (1994), Benziouche and Chehat (2010), Afrasinei *et al.* (2017a), Belghemmaz *et al.* (2018), and Abdelhafid, Rechachi and Halitim (2019), as well as Rechachi *et al.* (2021).

Algeria launched a number of programmes for agricultural development in the 1990s in hope to reduce fluctuations in oil revenues (Bessaoud *et al.*, 2019). Increasing irrigated areas in sectors perceived as strategic, such as date palms, fodder, and cereals in Saharan regions, is the goal of the agricultural renewal policy.

The Ziban region is the leading region in southern Algeria, with nearly 4 mln date palms (25% of the country's date palm heritage) and about 40% of market garden produce in the country is supplied by this region to the national market (Benziouche, 2017). The number of date palms is constantly increasing; according to Mihi, Tarai and Chenchouni (2017), it was 584,906 between 1984 and 2013.

The major changes in oasis management has already been pointed out by Dubost and Larbi-Youcef (1998). The authors stated that the Ziban region had gone from a multi-storey oasis to a monoculture of palm trees, with tunnel greenhouses erected next to the palm groves. For the past 30 years, this productivist approach to farming has dominated the Western Ziban (WZ); it seems that this so-called modern attitude relies exclusively on the over-exploitation of resources (water and soil) to increase crop productivity. It was therefore essential to better understand the impact of all these human-induced dynamics on the ZOE, and in particular on soil properties and pedogenetic processes. As a result, the question of how best to use the soil resources arises. Therefore, the major concern of this study was to provide valuable soil knowledge that will support the long-term management of these agroecosystems in the WZ. Hence, the objectives for this work were: (1) to characterise soils with a view to obtaining precise knowledge of their properties; (2) classify them in order to identify their typology based on the ST (2014) and WRB (2022) classification systems; (3) compare the outcomes of the two systems' typological units may be relevant; and (4) conduct remote sensing (RS) monitoring of these soils will provide insights into soil degradation, diversity, and functioning in interaction with environmental components.

MATERIAL AND METHODS

CONTEXT OF THE STUDY AREA

Location and landscape form

The Biskra region is situated in the northeast of Algeria, at the limit of the Sahara desert (34°51'0.00"N and 5°43'60.00"E). The study area is located west of Ziban (Biskra) between Ain Ben Noui and Tolga. Most of the Biskra region takes the form of a significant depression in the northern Sahara. This region's morphology is marked by three distinct morphological units: the mountain, the foothills, and the plain.

Main aspects of the oases agroecosystems environment

• **Climate and soils**

Living conditions in the Ziban region (Fig. 1) closely depend on climatic conditions (precipitation, temperature, wind, evaporation, and potential evapotranspiration). These factors determine the amount of water needed for irrigation (Aidaoui, 1994). This region has an arid climate – the average annual total received rainfall is about 200 mm but the annual mean rainfall is less than 30 mm (Pouget, 1980; Afrasinei *et al.*, 2017b). The status of soils in these oases is the result of a combined action of colluvium and aeolian transport. The prevalent wind direction goes from southeast to northwest along the Sahara Atlas. An arid (Torric) soil moisture regime has been identified in the WZ region. Ziban region's $A\ I = 0.11$ (Mihi, Tarai and Chenchouni, 2017).

• **Agriculture and ecology**

The Ziban region is one of Algeria's most important date palm cultivation areas (Benziouche and Chehat, 2010), with about 4 mln date palms. It is known for exporting the best quality "Deglet-Nour" dates. According to Benziouche and Chehat (2010) and Benziouche (2017), its palm groves are rich in biodiversity and contain at least 300 cultivars.

Seven of the top ten agricultural sites in the Biskra region are located in the western part of the Ziban. These areas, which include Tolga, Laghrous, Lichana, Bordj Ben Azouz, Lioua, El Hadjeb, and Bouchagroun, have the best-developed agroecosystems. Even though there is a chronic drought and severe heat, this arid region provides an essential ecological habitat for many different animal species. Moreover, we observed that only steppe grazing species, such as halophytic (*Salsola vermiculata*, *Tamarix gallica*, *Suaeda vermiculata*, etc.) and psammophytic communities (*Lygeum spartum* and *Aristida pungens*), contribute to the spontaneous floristic diversity.

DESCRIPTION OF THE OASES SITES AND SOIL SAMPLING

During the last decades, agricultural lands remarkably expanded in North African oases, including the Ziban region in the Algerian Sahara (Afrasinei *et al.*, 2017a) as a result of the sustainable water irrigation management adopted in oasis agroecosystems. The soils in the WZ region have gypsum accumulations, which Abdesselam (1991) and Belghemmaz (1991) attempted to characterise and map, whereas Bensaid (1999) has outlined their typology. Water and soil salinisation, alkalinisation, and waterlogging were the major processes encountered in this same region (Belghemmaz *et al.*, 2018).

Location of sampling profiles

The field work was carried out in June 2021 and aimed to provide preliminary observation of sand, surface state of each oasis with different agroecosystems. This investigation determined the location and GPS coordinates of the soil profiles (Tab. 1). Locations of the sampling profiles were chosen along two toposequences of around 30 km each, including the seven best oasis sites in the WZ region (Fig. 1).

Toposequence 1 extends from south east to south west and includes profiles that characterise the oasis sites of Oumache (P5), North Benthious (P6), and Ourlal (P1 and P2), as well as M'lili (P3 and P4). The sites of this toposequence are a part of the Oued Djedi's watershed, which discharges into the large depression that forms up the Chott Melghir.

Toposequence 2, which runs from north east to south west, includes the oasis sites of Ain Ben Noui (P9 and 10), El Hadjeb (P8), and the site P7 inside the palm trees in the south east part of Tolga (Fig. 1). The agroecosystem site represented by profile 7 is where the two toposequences converge.

Fieldwork

Our approach to all oasis sites aimed to identify the main aspects that characterise them. During this process, geomorphological and pedological criteria were examined, including the location of the oasis, shape of the landscape, morphological characteristics (soil colour and structure), presence or absence of saline efflorescences, formation of gypso-saline crusts or limestone crusts, or both, and the effects of wind erosion. The presence of the water table near the surface and the waterlogging phenomenon were additional crucial factors differentiating specific sites. This first level of observation allowed us to identify the dominant soil characteristics and define 10 homogeneous physiographic units. The oasis sites observed are distributed along two toposequences (Fig. 1); their soil profiles correspond to pits (not planted with palm trees) >1 m deep. Profile sections were refreshed to simplify observation, description, and sampling. A total of 27 soil samples were collected from the horizons

Table 1. Geographical position of soil profiles and main characteristics of oasis in the Western Zab of the Ziban region (Biskra), Algeria

Profile/Site	Coordinates and altitude (Alt.)	Main features described (land use, soil morphology, structure, erosion, etc.)
P1 Ourlal 1	34°39'03,76"N; 5°29'37,85"E Alt.: 130 m	recent plant in holes; young date palms; relief: glacis and topography with low slope; compact crust of limestone in the subsoil horizons (from 30 to 120 cm)
P2 Ourlal 2	34°39'35,36"N; 5°32'59,37"E Alt.: 114 m	new plantations; relatively compact horizons; degraded structure (swollen structure or pseudo-sand); natural vegetation: *Salsola*, *Atriplex*, and *Tamarix*; relief with gentle slope; presence of limestone crust
P3 Mlili 1	34°41'05,44"N; 5°37'31,11"E Alt.: 92 m	groundwater level around 8–10 m; "Deb Deb" crust (accumulation associated with $CaCO_3$ and gypsum); the presence of tuff on the soil surface; oasis composed of young palm trees and olive trees; very gentle slope; level of water table – 8–10 m
P4 Mlili 2	34°40'45,06"N; 5°37'28,12"E Alt.: 72 m	very well-developed palm grove (intercropping: associatied with olive and palm trees); absence of gypsum crust; limestone compact crust in the underlying horizons; sand aeolian accumulation
P5 Oumache	34°42'25,98"N; 5°41'00,86"E Alt.: 81 m	water table near the soil surface; abundant salt efflorescences; moist surface soil; development of halophyte species and *Tamarix* trees
P6 North Benthious	34°39'32,01"N; 5°28'52,99"E Alt.: 132 m	oasis site with palm and fig trees; soil covered by wind sands; *Tamarix* trees beside the oasis; absence of gypsum crust; good development of palm and understory crops
P7 South east Tolga	34°40'39,67"N; 5°26'48,04"E Alt.: 141 m	oasis site consisting of a young plantation of palm trees; "Deb Deb" crust; whitish appearance from the upper level to the lower level of the profile; crumbly on the surface and very compact in the subsurface and at depth
P8 South of El Hadjeb (Ain El Karma)	34°45'29,12"N; 5°31'20,51"E Alt.: 185 m	located 5–6 km west of El Hadjeb; within a well-developed palm grove; salt efflorescences covering the soil surface; presence of crust of "Deb Deb"
P9 El Hadjeb	34°47'38"N; 5°36'33"E Alt.: 175 m	the oasis El Hadjeb where the pedon is located is made up of date palms, vines, and fig trees; old well-developed palm grove; soil dominated by aeolian sand accumulation
P10 Ain Ben Noui (North ITDAS)	34°47'51"N; 5°37'09,89"E Alt.: 141 m	pedon is located near the Boughezal mountain's foothills and on its southern slope (near Institute of Saharian Agriculture Development: ITDAS); palm groves dominate vegetated areas; aeolian accumulation; visible and relatively abundant salt efflorescences

Source: own elaboration.

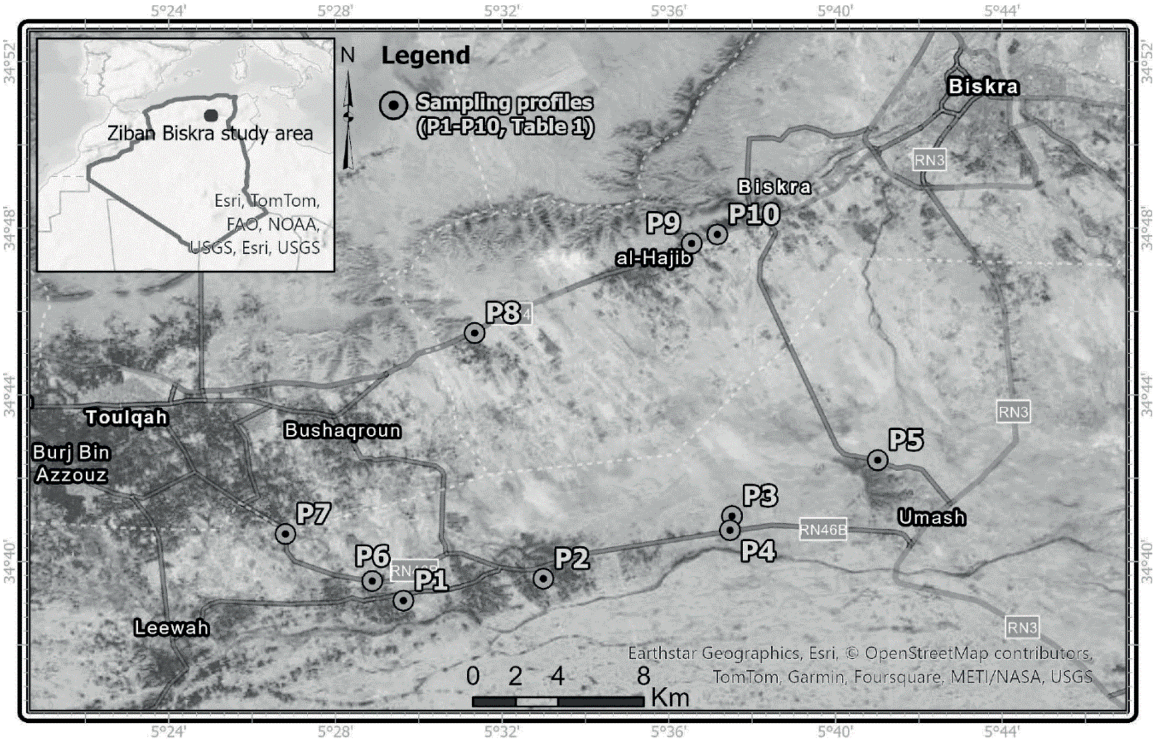

Fig. 1. Location of sampling profiles (P1–P10) in the Western Zab of the Ziban region (Biskra); P1–P10 characterised in Tab. 1; source: own elaboration

detected at different depths (0–30, 30–60 and 60–120 cm). The second observation level corresponds to the representative soil profile. Thus, to identify the epipedons and diagnostic horizons of the subsoil, the qualitative data collected at each pedon is combined with analytical data. Table 1 demonstrates that the majority of oasis locations exhibit salt efflorescences. However, the absence of any drainage network activities in the farms or neighbouring oases is particularly noteworthy.

SOIL ANALYSIS

Soil analyses were performed using the methods described by Mathieu and Pieltain (2003) and Bashour and Sayegh (2007). Soil samples were air-dried, ground, and sieved through a 2 mm sieve.

Physical and chemical characterisation

Particle size distribution was determined by the pipette method in a sedimentation cylinder using sodium hexametaphosphate as a dispersant. Considering the soil properties of these ZOE, the presence of gypsum presented a significant analytical limitation for separating particles from the soil, so the Vieillefon (1979) method is applied to prevent flocculation of the suspension; samples should be treated with a barium chloride solution to create coatings of barium sulphate on gypsum particles.

The pH of soil solutions was measured with a 1:2.5 diluted extract (pH meter 3310 JENWAY). Electrical conductivity (*EC*) was measured using a conductivity meter (Cond 7110 inoLab) on a 1:5 diluted extract. Total $CaCO_3$ was obtained using the standard Bernard calcimeter, and gypsum content was determined gravimetrically. Organic carbon (OC) was measured using Anne's method, and the soil organic matter content (OM) was calculated. Three cations (Ca^{2+}, Na^+, and K^+) were measured in a 1:5 diluted extract using a flame spectrophotometer, while bicarbonate and chloride were measured in the same extract using standard titration. Magnesium is determined by atomic absorption spectrophotometry (PFP7 Flame Photometer JENWAY), and sulphate is determined by UV-visible spectrophotometry (Unicam Helios Delta UV Visible Spectrophotometer).

International soil classification systems

The International Union of Soil Sciences (IUSS) has recognised ST and WRB as the two most widely used soil classification systems (Salehi, 2018). Hence, the typology of soil resources in the study area was provided using these two systems.

REMOTE SENSING

To assess salinisation of these agroecosystems, we considered the spectral analysis of 1984, 2015, and 2016 Landsat images, along with the land cover classification methodology and nomenclature described in literature (Afrasinei *et al.*, 2017a; Afrasinei *et al.*, 2017b; Afrasinei *et al.*, 2018; Lamqadem, Afrasinei and Saber, 2019; Belghemmaz *et al.*, 2018). Salt features and main land cover classes of 2016 extracted using a custom decision tree are presented in the "Remote sensing analysis section".

RESULTS AND DISCUSSION

PHYSICOCHEMICAL CHARACTERISATION OF SOILS

Soil reaction (pH)

The pH values for the surveyed sites vary and range from 7.47 to 8.56. They indicate that the soil is generally alkaline. Profiles 5 and 7 present a value of ≥8 (Tab. 2). These pH values may indicate increased availability of K, S, Ca, and Mg nutrients, but

Table 2. Soil physico-chemical characterisation of oasis agroecosystems in the Western Zab of the Ziban region (Biskra), Algeria

Pedon (P)	Horizon (H)	Soil chemical analyses					Soil texture and organic matter (OM)	
		depth (cm)	pH (water)	*EC* ($dS \cdot m^{-1}$) at 25°C	$CaCO_3$ (%)	gypsum (%)	OM (%)	texture
P1	H1	0–30	7.67	5.35	13.26	32.71	0.53	SL
	H2	30–60	7.77	10.15	16.96	24.70	0.95	SL
P2	H1	0–30	7.77	2.55	8.26	33.91	1.16	SL
	H2	30–60	8.00	22.15	11.09	30.87	1.38	SClL
	H3	60–120	7.475	19.49	11.30	33.20	0.85	SClL
P3	H1	0–30	7.58	4.34	17.61	19.17	0.11	SL
	H2	30–60	7.72	8.74	24.35	43.63	0.42	SL
P4	H1	0–30	7.54	4.00	12.72	10.33	0.74	SL
	H2	30–60	7.51	17.29	13.26	10.16	2.01	SL
P5	H1	0–30	8.20	30.00	3.91	47.80	1.59	L
	H2	30–60	8.13	12.64	2.93	37.52	0.53	L
	H3	60–120	8.41	7.23	6.20	32.40	0.11	L
P6	H1	0–30	7.91	4.47	6.30	47.37	0.63	L
	H2	30–60	7.76	3.11	7.07	56.91	0.63	L
	H3	60–120	7.60	2.39	7.50	56.37	2.01	L
P7	H1	0–30	8.56	8.89	0.00	85.43	0.42	SCl
	H2	30–60	8.46	3.10	0.02	85.48	0.53	SCl
	H3	60–120	8.05	2.58	0.00	87.48	0.53	SCl
P8	H1	0–30	7.70	2.58	8.48	29.04	0.53	SL
	H2	30–60	7.60	2.25	9.78	10.60	0.32	SL
	H3	60–120	7.59	2.08	9.78	29.69	0.53	SL
P9	H1	0–30	7.52	4.44	14.24	17.76	1.80	SL
	H2	0–60	7.55	2.28	11.09	17.36	1.38	SL
	H3	60–120	7.55	15.39	15.43	4.28	1.80	SL
P10	H1	0–30	7.50	5.33	3.91	43.04	0.42	SCl
	H2	30–60	7.82	2.39	10.65	31.12	0.85	SCl
	H3	60–120	7.71	2.19	13.04	17.03	1.59	SCl

Explanations: *EC* = electrical conductivity, SL = sandy loam, L = loam, SCl = sandy clay, SClL = sandy clay loam.
Source: own study.

not the availability of micronutrients (McCauley, Jones and Olson-Rutz, 2017). High pH prevents Fe or Zn transfer to plants, according to Moreno-Jiménez *et al.* (2022) and citations there in.

Soil salinity

Concerning salinity, we note that *EC* can also vary and range from 2.08 (P8H3) to 30.00 $dS \cdot m^{-1}$ for P5H1. It should be noted that low salinity oases are characterised by generally very low $CaCO_3$ content associated with gypsum deposition in the form of surface crust. In these arid agroecosystems, the upward movement of water and its evaporation from the soil surface leads to salt accumulation. This salt accumulation explains the increase in *EC* values, especially at most surface and subsurface horizons. Many soluble salts, including major ions such as Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, CO_3^{2-}, and SO_4^{2-}, are present in saline soils in significant amounts (Andrade Foronda and Colinet, 2023), but NaCl is the most prevalent salt (Rengasamy, 2002; Munns and Tester, 2008). However, the high salinity of P5 is due to groundwater near the surface. The topographic position of the oases represented by P3, P4, and P5, located in places that are part of the depression, might be a factor in soil degradation due to either salinity or waterlogging, or both. Such problems can affect the production of various crops within these agricultural area; the development of date palms and their production may also be compromised. Hence, managing these soils is a challenge because Shahid, Zaman and Heng (2018) believe that due to this unfavourable topography, including lower part of the landscape or places with very gentle slope, leaching is bound to cause problems.

Calcium carbonate and gypsum accumulation

The content of calcium carbonate in these soils varies from place to place; in profiles P5, P6, P7, and P8, it ranges from low to very low, with median values <10%. In other locations, however, the profiles are moderately calcareous. Omar and Shahid (2013) reported that deficiency problems due to the calcareous nature of soil could affect the availability of nutrients: P, Mo, Fe, Zn, and Mn.

The gypsum content is a criterion for gypsic and petrogypsic horizons and for mineralogical class at the family level (Soil Survey Staff, 2014). All soil profiles in the oases studied contain gypsum. It should be noted that almost all of the samples gypsum content ≥10%, and the accumulation of this element becomes excessive with rates ≥85%, particularly in profile 7, where a gypsum crust is observed; this formation is locally named "Deb Deb". Gypsum feels dynamics both in the profile and in the landscape. According to Porta (1998) as cited in Azizi *et al.* (2011, p. 1), this movement results from the dissolution of salt in water and the release of ions that move into the soil or across different landforms. Accordingly, gypsiferous soils are generally found in flat to hilly lands or depressions, as noted by Boyadgiev and Verheye (1996).

Precipitation and dissolution of gypsiferous parent material are the main pedogenetic mechanisms that may lead to gypsum formation and accumulation in these soils at different landscape levels. Gypsum content increases with depth, reaching a maximum in all pedons at around 30–80 cm, and decreasing again in the lower parts of the soils. According to Aizizi *et al.* (2011), these dynamics imply that gypsum is leached during wet periods and rises by capillarity during dry periods. According to these authors, $CaSO_4{\cdot}2H_2O$ in sufficient quantities affect soil properties and behaviour, and cause several problems such as plant growth and crop production.

SOIL TEXTURE AND ORGANIC MATTER

The sand fraction dominates the soil texture in the study area. Clay and silt levels are notably low (≤30%); they are even null in profiles 4, 5, 6, 7, and in the upper horizons of profile 10. This absence shows a significant deposition of sand particles at the sites. The OM contents are very low and remain largely <2%. These low amounts of OM can also be explained by the low input of OM and strong mineralisation of humic substances in this arid context.

PEDOLOGICAL AND ENVIRONMENTAL CONSTRAINTS OF THE OASIS AGROECOSYSTEMS

Pedological constraints

- **Soil salinity**

During the dry season, field observations revealed an accumulation of salt in the form of saline efflorescences that covered surfaces of profiles 1, 2, 5, 8, and 10, as well as their different horizons. Due to high water solubility, chloride salts ($NaCl$, KCl, $MgCl_2$) and even $MgSO_4$ are very mobile in soil. The other salts, such as gypsum, are either slightly soluble or little soluble, e.g. $CaCO_3$ (Karakouzian *et al.*, 1996). Gumuzzio and Casas (1988) stated that these salts fill channels in the soil. Drylands become salinised due to excessive irrigation and in places with shallow saline water tables (pedons 3 and 5). The existence of a likely salty water table at a shallow depth, with high levels of ions, is related to the salic horizon in pedon 5. This water table rises to the surface during wet months, dissolving salts and saturating the soil. By contrast, pedon 3 has not developed a salic horizon because the water table is intermittent, rising with wet conditions (irrigation or precipitation) and falling with high evaporation. Fernández-Cirelli *et al.* (2009) stated that implementing irrigation in arid and semiarid environments inevitably leads to changes in the water table, frequently resulting in waterlogging and secondary salinisation. We believe that the spread of secondary salinisation from nearby palm plantations might have led to the increase in salinity. Due to agricultural practices (poor drainage, chemical fertilisers, irrigation), salinisation is expanding more rapidly than it would naturally. Many farmers have been compelled by this process to leave the WZ region's degraded oases.

- **Gypsum accumulation**

The most prevalent sulphate mineral in the study area's soils is gypsum, found in profiles 2, 3, 6, and 7, where we identified gypsic and petrogypsic horizons. In pedons 2, 3, 7, and 8, we observed a specific pedological feature linked to the cemented structure of gypsum, reflecting the formation of soils with gypsum crusts and encrustations. Although profiles 5 and 10 occasionally contain gypsum ≥40% (P5H1 and P10H1), the soils in these areas did not have any features that would suggest the presence of a gypsum crust or crusting.

Gouskov (1964) highlighted the presence of a calcareous-gypseous crust on the transect, relating the oasis of Ain Ben Noui, El Hadjeb, to the palm trees of Tolga and its surroundings. According to this source, this "Deb Deb" structure was formed during the Medium Quaternary deposit process. The structure still remains active now. The "Deb Deb" type crust that we have described on the toposequence 2, precisely in the oasis sites of El Hadjeb (P8) and south east of Tolga (P7), has also been highlighted by Abdesselam and Timechbache (2016). An identical "Deb Deb" formation can be found on toposequence 1 at the M'lili 1 site (P3). According to Coque (1964), Pouget (1968), and Abdesselam and Timechbache (2016), this specific formation involves the deposit of gypsum and limestone, and owes its genesis to the effect of the saline water table.

- **Calcareous**

Naorem *et al.* (2023) noticed that although calcareous soils may appear in good physical condition, significant chemical changes occur once irrigated. These authors asserted that crust development, controlled by such factors as texture and salt dominance, increases with the dissolution of carbonates into bicarbonates and the subsequent precipitation of the latter upon drying. However, the emergence of the limestone crust is remarkable at various levels of the soil profile in most of the agroecosystem sites. The same occurs in the oases represented by P3 and P7. Regarding the benefit of $CaCO_3$ in saline soils, Visconti and Paz de (2012) reported that when calcium, bicarbonate, and/or sulphate are sufficiently concentrated in irrigation water, the precipitation of calcite and gypsum prevents the salinity of the soil solution from reaching harmful values.

Climatic constraints: Wind effect and sand encroachment

This section focuses on the current status of sand accumulations due to wind sand and how they affect the oasis agroecosystems of the Ziban rather than on sand encroachment and the dynamics of dunes. Haouchine (2010) reported that the highest yearly velocity frequently attained in April is 5.7 $m \cdot s^{-1}$ and that the annual velocity is roughly 4.5 $m \cdot s^{-1}$. Sirocco winds, with an average frequency of 58 days per year, dominate the south-eastern area of Biskra.

Being dry and violent, the siroccos winds harm pastures and oasis crops. Aeolian sands are visible at almost every site under investigation. These accumulations often occur in areas with obstacles, such as live or inert windbreaks, and appear in various forms. Sand piles and little dunes were found in oases 9 and 10. According to Naorem *et al.* (2023), high wind speeds, frequent droughts, persistent water shortages, and faster evaporation rates than precipitation are typical features of arid environments. Biodiversity loss may occur when desertification develops, and previously non-arid areas become arid.

SOIL TYPOLOGY

Classification of soils according to WRB 2022

The typological study of the soils using the WRB 2022 acc. to IUSS Working Group WRB (2022) for soil resources allowed us to observe a spatial variability of pedodiversity. Reference soil groups (RSGs), which include Arenosols, Gypsisols, and Solonchaks, are the most common types. The soils in the study area are classified as shown in Table 3. The classification is based on soil morphology (colour and structure) and laboratory analytical data pertaining to soil units, diagnostic horizons, and other diagnostic criteria (Tab. 2). Furthermore, it is illustrated how this typology corresponds to the USDA's soil taxonomy (USDA, 2014).

RSG of Solonchaks: such soils have been observed at sites in toposequence 1, forming part of the Oued Djedi watershed. The soils are characterised by a variable accumulation of soluble salts. All the pedons in this oasis environment meet the criteria of the preponderance of ochric epipedon and the presence of gypsic and salic diagnostic horizons (Tab. 3). In addition to their main characteristics, these soils show the association with other features related to the presence of gypsum and secondary carbonates, i.e. an aeolian deposit. Hence, we have distinguished two soil types with their main qualifiers: Gypsic Solonchaks (hypersalic) in P2 and P5, and Yermic Gypsic Solonchaks in P4.

The formation of the salic and gypsic horizons in these areas is thought to have taken place in two ways: (1) it involves an earlier formation due to a natural deposition of salts by evaporation; the presence of the water table might have influenced this process; (2) it is related to the advanced anthropisation of the soils in these oasis agroecosystems. Irrigation water and soil management problems amplify secondary salinisation. In addition, the topography of most of these sites

Table 3. Summary of the morphological and diagnostic features of surface epipedons and subsurface horizons in the Western Zab of the Ziban region (Biskra), Algeria

<table>
<tr><th rowspan="2">Pedon No.</th><th colspan="3">Diagnostic horizons and other features, properties, and materials</th></tr>
<tr><th>USDA (2014)</th><th>IUSS Working Group WRB (2022)</th><th>soil colour (dry) acc. to Munsell Color Company (2014)</th></tr>
<tr><td>P1</td><td>ochric epipedon,
gypsic (By) in the subsoil (30–60 cm; P1H2)</td><td>gypsic (gy) at the subsurface layer (P1H2)</td><td>7/4 7.5YR (H1)
7/3 7.5YR (H2)</td></tr>
<tr><td>P2</td><td>ochric epipedon,
gypsic (Cy) between 30–120 cm; P2H2 and P2 H3</td><td>salic (sz) in PH2 horizon</td><td>7/4 7.5YR (H1)
6/1 10YR (H2)</td></tr>
<tr><td>P3</td><td>ochric epipedon,
gypsic (Cy); (30–60 cm P3H2)</td><td>gypsic (gy) developing from 30 cm</td><td>7/3 10YR (H1)
8/1 10YR (H2)</td></tr>
<tr><td>P4</td><td>ochric epipedon,
gypsic (By) in the subsoil (30–60 cm; P4H2)</td><td>salic (sz)</td><td>6/3 7.5 10YR (H1)
7/3 10YR (H2)</td></tr>
<tr><td>P5</td><td>salic horizon (Az) at the surface (0–30 cm; P5H1).</td><td>hypersalic (jz)</td><td>6/3 7.5YR (H1)
7/4 7.5YR (H2)</td></tr>
<tr><td>P6</td><td>ochric epipedon,
gypsic (By) and (Cy) between 30–120 cm (P6H2 and P6 H3)</td><td>hypergypsic (jg)</td><td>7/2 7.5YR (H1)
8/2 7.5YR (H2)</td></tr>
<tr><td>P7</td><td>ochric epipedon,
petrogypsic (Cyy)</td><td>hypergypsic (jg)</td><td>8/2 10YR (H1)
8/1 2.5YR (H2)</td></tr>
<tr><td>P8</td><td>gypsic (Cy); cemented horizon but not meeting petrogypsic criteria (gypsum<40%)</td><td>gypsic (gy)</td><td>8/2 10YR (H1)
7/3 10YR (H2)</td></tr>
<tr><td>P9</td><td rowspan="2">ochric epipedon
predominance of mineral material (particularly sand) and absence of distinct soil-genetic horizons</td><td>slight differentiation of soil profile layers; sandy texture</td><td>7/4 7.5YR (H1)
7/3 7.5YR (H2)</td></tr>
<tr><td>P10</td><td>sandy, coarse texture, deep, and gently sloping; soil with no discernible profile differentiation</td><td>8/3 7.5YR (H1)
7/3 10YR (H2)</td></tr>
</table>

Explanations: the norms of Soil Survey Staff (2014) for soil taxonomy are followed with the use of diagnostic horizon (DH) symbols and designations. The ones that represent DH for WRB classification are in accordance with the recommendations of the IUSS Working Group (2022). The bolded symbols are used acc. to USDA (2014) and to WRB (2022).
Source: own study.

is not favourable to natural drainage of excess irrigation water. Poor drainage or its absence can increase the accumulation of salts and waterlogging in low-lying areas (Belghemmaz *et al.*, 2018).

The RSG Gypsisols*:* these have been identified along the two toposequences; pedons 2, 3, 6, 7, and 8 are characterised by a notable accumulation of gypsum (30–87%). They also combine other aspects of salinity and moderate limestone accumulation. Based on the form of gypsum accumulation and the presence or absence of induration, four main types of gypsiferous soils have been identified: a) Haplic Gypsisols (aeolic) in P8; b) Haplic Yermic Gypsisols (protosalic) in P1; c) Haplic Yermic Calcic Gypsisols (protosalic) in P3; and d) Haplic Gypsisols (hypergypsic) are found in sites represented by P6 and P7. They are soils with substantial accumulation of secondary calcium sulphate. Rechachi *et al.* (2021) noted the occurrence of these soils in western Zab, particularly in the Tolga El Hadjeb and Lioua oases, confirming their abundance in this part of Ziban.

Except for the subsurface horizon of pedon 7 (P7H2), which shows a hue of 2.5Y (Tab. 3), morphological features and soil OM contents of the Gypsisols found in this research are comparable to those obtained in the Middle Ebro Basin of Spain by Aznar *et al.* (2013). These authors indicated that the horizons of such soils mainly reveal a 10YR hue, with values between 6 and 8, and chroma from 1 to 3 (light gray and light brownish gray). This similarity might be explained by most of the horizons having high gypsum concentration and low soil OM content.

It should be noted that even when the classification includes diagnostic criteria (% gypsum and $CaCO_3$, *EC*, and texture), too many similarities between specific profiles of the ten sampling sites makes it challenging to switch from one RSG to another. It is important to note that the gypsiferous soils at the sites are found in specific geomorphological positions that promote endorheism. Canton *et al.* (1996), Roquero and Perez Arias (1996), and Herrero and Boixadera (2002) showed that the nature of the reliefs, slope effect, and the amount of time it takes for the substrate to stabilise are the main causes of this situation.

The RSG of Arenosols: they are widespread in arid and semiarid regions (IUSS Working Group WRB, 2022). The parent material of Arenosols is unconsolidated and contains translocated components with a sandy texture, part of which is calcareous. They often have little or no soil development in arid environments (IUSS Working Group WRB, 2022). Arenosls are represented by two main soil types, i.e. Gypsiric and Yermic (Endosalic, protogypsic) which was identified in P9 and has a maximum salinity (15.39 $dS\cdot cm^{-1}$) at depth; Gypsiric and Yermic Arenosols (protocalcic) in P10, which has low salinity in the lower horizons and moderate salinity (5.33 $dS\cdot cm^{-1}$) at the surface. These particular soil types were found on the Djebel Boughezal foothills (P10 at the Ain Ben Noui site) and the El Hadjeb site (P9). This mountain range forms a natural barrier, and its slopes are a receptacle for aeolian sand.

Classification of soils according to soil taxonomy of USDA (2014)

Diagnostic horizons identified in the study area (Tab. 3) include: a) surface horizons, with ochric epipedon dominant at all sites in the two toposequences; and b) subsurface diagnostic horizons, comprising gypsic, petrogypsic, and salic horizons. Although almost half of the soil samples contain from 9.78% to 24.35% $CaCO_3$, likely to give rise to a calcic horizon, this diagnostic horizon could not be detected in these pedons. The absence of a calcic horizon does not agree with findings by Boyadgiev and Verheye (1996) and Toomanian, Jalalian and Eghbal (2003). These authors highlighted the possible occurrence of gypsic and calcic horizons together and with or without the salic horizon in the soils of arid regions containing carbonated pedological material. Thus, the soil orders identified included Aridisols and Entisols.

Aridisols: these are divided into Gypsids and Salids. These suborders (SO) reflect the relative abundance of gypsiferous and saline accumulations. Calcids were not found in the study area's soil landscape. The SO of Gypsids: Typic Haplogypsids have been distinguished for pedons P1, P2, P3, P4, P6 and P8. These soils present only a gypsic horizon consisting of the accumulation of secondary (soft) gypsum without induration.

Unlike Typic Haplogypsids, a petrogypsic horizon has emerged from the accumulation of secondary gypsum in the diagnostic horizon, and the gypsum crust becomes highly compact. This soil type was located in oasis site 7. The SO of Salids: In addition to the salic horizon identified in Pedon 5, the soil is further distinguished by an increased accumulation of soluble salts. Thus, we identified the great group (GG) of Haplosalids with one (subgroup) (SG): Gypsic Haplosalids for pedon. The Oumeche site (P5) is the lowest (81 m) of all the sites studied, and it also has the highest soil salinity (P5H1), with an *EC* of 30 $dS\cdot m^{-1}$.

The petrogypsic horizon of pedon 7 and the gypsic horizon of pedons 1, 2, 3, 4, 6 and 8 have a laterally continuous, cemented structure. It has been suggested that these horizons were formed by the dissolution of calcium sulphate during the rise of the water table. Gypsum crystallisation and deposition occur when the level of the aquifer unit falls during the dry season. Gypsum may also undergo translocation in irrigated areas. The same process was referred to by Pouget (1968) to explain the origins of gypsum-crusted soils in Tunisia.

However, Nesson (1978) reported that at least 80 important water sources existed in the WZ region at the start of the 19th century, especially in the oasis of Tolga and its surrounding areas. This author emphasises that water nappes (phreatic groundwaters) were active at this time, including the calcareous nappe with calcium sulphate facies and the phreatic aquifers (shallow groundwaters) with mixed-chemical sulphate facies. Owing to their chemical facies, these aquifer units' hydrochemical quality would have allowed the formation of gypsic and petrogypsic horizons by enriching the soil profile with salts such as gypsum. According to the Soil Survey Staff (2014), the non-leaching of soluble salts, including gypsum, at depth is a required for this pedogenetic process.

According to Halitim (1988), the gypsic and petrogypsic horizons were formed by the intrusion of gypseous accumulation into the original soil material to form the gypsiferous nappe crusts. Gypsum precipitation in the macropores and the production of the pedo-features seem to result from the dissolution of gypsum in the surface horizon sand the continual movement of calcium and sulphate ions in the soil percolation water. According to Halitim (1988), Hashemi, Baghernejad and Khademi (2011), and Pashaei and Manafi (2021), this is the most common mechanism that forms gypsum pedo-features in gypsiferous soils.

Entisols: in ST, the parent material is the most significant factor to partially identify Entisol suborders produced from fluvial or sandy materials (e.g., Fluvents and Psamments) (Bockheim *et al.*, 2014).

Only the SO of Psamments and the GG of Typic Torripsamments were found. These are eolian sand accumulation soils, represented in pedons 9 and 10, which occupy the upper part of the landscape, more precisely at the foothills of the Boughezal Mountain.

Nordt *et al.* (2011) point out that similar soils were found in Saudi Arabia with less than 100 mm of rainfall and pH > 8.5. According to Omar and Shahid (2013), the Typic Torripsamments observed in the south of Kuwait were similar to the Typic Haplocalcids. Nevertheless, based on research so far, no characteristics of the Typic Haplocalcids were found that match those of the Typic Torripsamments described in the Ziban region. The colour of the surface horizon is 7/4 7.5YR (P9H1) and 8/3 7.5YR (P10H1); they are composed of sand, gypsum, and even $CaCO_3$ and quartz. Most of the natural vegetation is composed of halophytic and xerophytic plants.

The limestone present in many parts of the study area underwent gypsification. This process may explain the appearance of the gypsum-calcareous crusts known in local jargon as "Deb Deb". Given the main aspects revealed by the Gypsic Haplosalids encountered in pedon 5 of this study, we can affirm that this soil type is almost identical to the Haplosalids with gypsum accumulation identified by Abdelfattah and Shahid (2007) in the context of the arid zone of Abu Dhabi of the UEA.

COMPARISON OF SOIL TYPOLOGY IN SOIL TAXONOMY AND WRB 2022

Calcisols and Gypsisols occur in the same climate zone. It should be highlighted that while a gypsic or petrogypsic horizon is diagnostic of gypsisols, gypsum accumulation may also be observed in other RSG (Driessen and Deckers (eds.), 2001). A calcic horizon exists above the gypsic or petrogypsic horizon in many sampling locations in Kuwait (Omar and Shahid, 2013). We only determined Haplogypsids and Petrogypsids because the Gypsids identified in the research area do not present a calcic horizon above the gypsic or petrogypsic horizon.

Furthermore, Moret-Fernandez *et al.* (2021) revealed the presence of Typic Haplogypsids and Gypsic Haplosalids in semiarid climate in NE Spain. These gypsiferous soils are low in OM (1.94%), have pH of 7.84 and a sandy-loam texture (Moret-Fernandez *et al.* 2021; Navarro-Perea *et al.*, 2023 and citations therein). The Typic Haplogypsids observed in the WZ (P1, P2, P3, P4, P6 and P) are almost similar to those described. However, the Gypsids Haplosalids (P5) in our study area show an alkaline pH (8.1 and 8.4) that is significantly higher than that of the identical soil type in NE Spain.

Torripsamments are similar to the Arenosols regarding material parental, lack of profile development, and texture dominated by sands. They occur in this area with characteristics nearly similar to those described by ST (1999 and 2014). These soils are distinctive in that they are often located at the top of the landscape and are the receptacle of sand aeolian deposits. The top 120 cm of these soils do not include any diagnostic subsurface horizons.

Toomanian, Jalalian and Eghbal (2003) classified gypsiferous soils in north-western Isfahan (Iran) using the ST and WRB systems. In their opinion, the ST still had shortcomings that prevented it from being able to compete with the WRB approach in classifying the gypsiferous soils. However, according to Sarshogh (2010), as cited in Rasooli *et al.* (2021, p. 220), who studied the soils in the Babaheidar region of western Iran, the ST system (Soil Survey Staff, 2010) could better describe the features of shallow soils in semiarid regions when compared to the WRB system (IUSS Working Group, 2022).

It is also interesting to note that the WRB has identified pedon 4 (P4) as a Yermic Gypsic Solonchaks (Fig. 2). The descriptive and analytical aspects of this pedon are highlighted by the Gypsic and Yermic qualifiers. However, in the ST, P4 is much

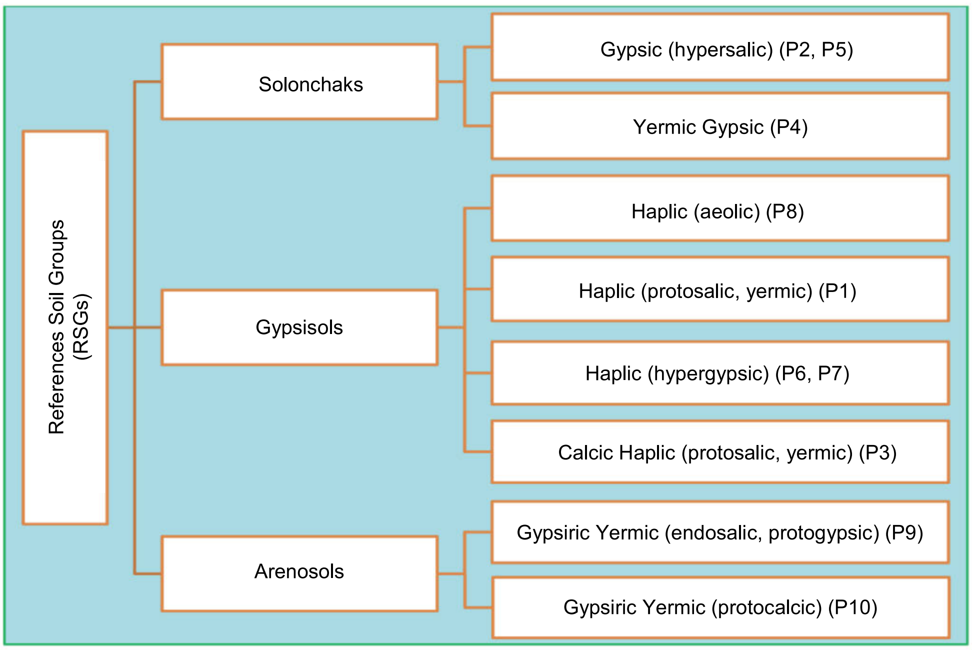

Fig. 2. Soil typology according to IUSS Working Group WRB (2022) in the Western Zab of the Ziban region (Biskra), Algeria; source: own study

more influenced by salinity than by gypsum accumulation. In view of the ST criteria, this pedon does not meet the conditions for the development of a salic diagnostic horizon between 0 and 100 cm (Tab. 3). Since it differs from P5, it should be classified as Typic Haplogypsids rather than Gypsic Haplosalids. Regarding P5, despite being classified as Gypsic Solonchaks (hypersalic) in the WRB, its classification as Gypsic Haplosalids seems more appropriate when compared to Typic Haplosalids (Fig. 3). This is because P5 has a significant deposit of secondary gypsum (32–47%) in addition to the salic horizon that appears in the ST. Pedon 2 is classified as a Gypsic Solonchaks (Hypersalic) and P5 depending on the colour and lightness, grain size, humidity and nature of the mineral soil surface.

High reflectance values corresponded to either light-coloured, fine, or dry soils (whitish gypsum sands, gypsum crust, aeolian and alluvial sands); the lower reflectance values represent dark, rough, or high moisture-content surfaces (wet saline surface sand Sebkha open-water surfaces). In addition, the surfaces with veils of aeolian sands (with a dominance of quartz), which have been described in the various Ziban sites, could easily be mapped, regardless of their position in the landscape, as shown in similar bio-geo-physical study areas and works in North Africa (Afrasinei *et al.*, 2018).

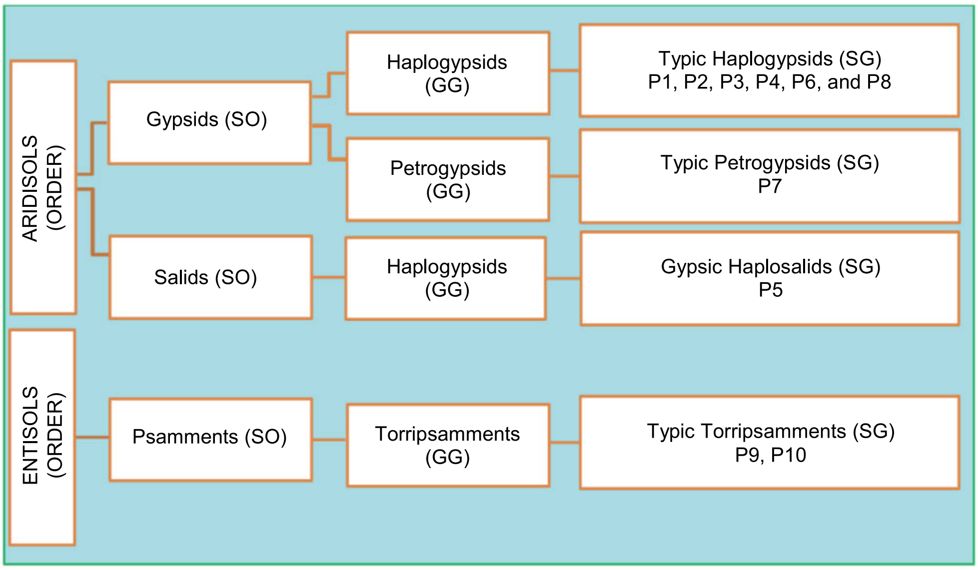

Fig. 3. Soil typology according to soil taxonomy of the USDA (2014) in the Western Zab of the Ziban region (Biskra), Algeria; note: in the left to right columns, the boxes refer to the order, suborder, great group, and subgroup levels in soil taxonomy; source: own study

(WRB); they are characterised by high salinity between 60 and 120 cm and a degraded structure (Tab. 1). The ST classification does not follow that of P5; it is therefore classified as a Typic Haplogypsids and not a Gypsic Haplosalids. The rate of gypsum (>30%) has given rise to a gypsic horizon that meets the criteria of Soil Survey Staff (2014).

Regarding the two classification systems, ST and WRB, our conclusion is consistent with that of Zayed *et al.* (2023): the two systems are complementary and, hence, beneficial together. We added that using them provides a wide range of information about the features and typology of the soils studied.

REMOTE SENSING ANALYSIS

Following the methodology (Afrasinei *et al.*, 2017a; Afrasinei *et al.*, 2017b), eleven spectral indices were used and thresholds were determined using the mean and standard deviation of each index image (Afrasinei *et al.*, 2017b; Afrasinei *et al.*, 2018; Belghemmaz *et al.*, 2018) – Figure 4. These indices were specifically designed to address spectral confusion problems brought on by the extraction of highly reflecting desert features and land cover characteristics of arid regions. The twelve extracted classes are presented in Figure 4 followed by their descriptions (Afrasinei *et al.*, 2017a). According to Hadj-Kouider, Eddine Nezli and Belhadj (2017), the class-related spectral responses enable to highlight different spectral classes. It was found that the reflectance curves varied

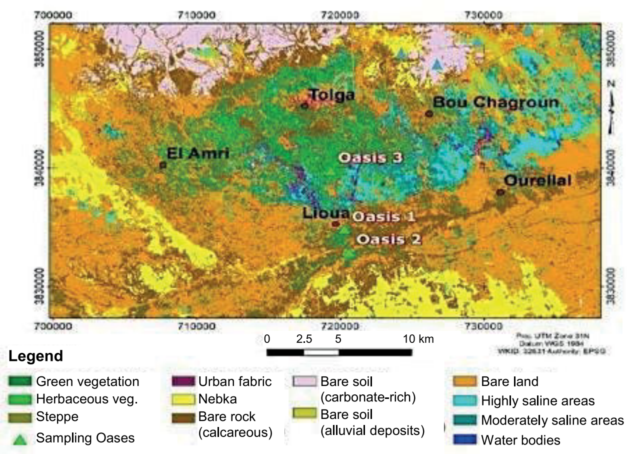

Fig. 4. Decision tree classification (April 2016 Landsat image, Biskra); source: own study

CONCLUSIONS

1. Field surveys and pedological characterisation of the ten sampling profiles revealed the soil morphological, physical, and chemical properties and their functioning in extreme aridity and intrinsic and environmental constraints.

2. Identifying spatial diversity of soils along the two toposequences was possible. The predominant soil types in the WRB (RSGs) were Gypsisols, Solonchaks, and Arenosols. The Gypsids, Salids, and Psamments were suborders of the ST. Gypsiferous soils were widespread in the Western Ziban (WZ).
3. Human activity and climate change have affected soil diversity. The monitoring of agroecosystems indicated that salinisation can still evolve due to soil overexploitation and poor farming practices. Salinity is a major issue in the WZ, and its exacerbation is visible on pedons 1, 2, 4, and 5. This may indicate a shift of secondary salinisation danger to new oasis areas. However, wind erosion threatens WZ's oasis ecosystem.
4. Improving soil management (irrigation, drainage, understories cultivation) is necessary to sustain these agroecosystems. To preserve these centuries-old systems' productivity, agroecological approaches must be gradually adopted.
5. Soil characterisation and typology help decision-makers and farmers choose the best management strategy for each situation by distinguishing and designating degraded areas based on their nature, degree, and soil characteristics.
6. Farmers are advised to employ conservation agriculture methods, using less input, proper ploughing, effective water management, wind erosion protection, and soil cover crops to prevent excessive evaporation.

CONFLICT OF INTERESTS

All authors declare that they have no conflicts of interests.

REFERENCES

Abdelfattah, M.A. and Shahid, S.A. (2007) "A comparative characterization and classification of soils in Abu Dhabi Coastal Area in relation to arid and semi-arid conditions using USDA and FAO soil classification systems," *Arid Land Research Management*, 21(3), pp. 245–271. Available at: https://doi.org/10.1080/15324980701426314.

Abdelhafid, Y., Rechachi, M.Z. and Halitim, A. (2019) "Caractérisation géochimique des eaux d'irrigation de la palmeraie d'Oumache (oasis des Ziban, sud-est de l'Algérie) [Geochemical characterization of the irrigation water of Oumache's palm grove (Ziban oasis, South-eastern Algeria)]," *Revue des sciences de l'eau*, 32(1), pp. 69–81. Available at: https://doi.org/10.7202/1059881ar.

Abdesselam, S. (1991) *Contribution à l'étude des sols à accumulations gypseuses de la région de Ain-Benoui (Biskra). Essai sur la micromorphologie des sols [Contribution to the study of gypsum-accumulated soils in the Ain Ben Noui region (Biskra). Essay on soil micromorphology]*. BAgr. Thesis. Batna: Univ. of Batna.

Abdesselam, S. and Timechbache, M.L. (2016) "Sur la nature et l'origine de la croute gypseuse dite «deb deb» dans les palmerais de l'ouest des Ziban [On the nature and origin of the "deb deb" gypsum crust in the western Ziban palm groves]," *Algerian Journal of Arid Environment*, 6(1), pp. 87–95.

Afrasinei, G.M. *et al.* (2017a) "Assessment of remote sensing-based classification methods for change detection of salt-affected areas (Biskra area, Algeria),"*Journal of Applied Remote Sensing*, 11(1), 016025. Available at: https://doi.org/10.1117/1.JRS.11.016025.

Afrasinei, G.M. *et al.* (2017b) "Classification methods for detecting and evaluating changes in desertification-related features in arid and semiarid environments," *Euro-Mediterranean Journal for Environmental Integration*, 2(1), 14. Available at: https://doi.org/10.1007/s41207-017-0021-1.

Afrasinei, G.M. *et al.* (2018) "Spatiotemporal and spectral analysis of sand encroachment dynamics insouthern Tunisia," *European Journal of Remote Sensing*, 51(1), pp. 352–374. Available at: https://doi.org/10.1080/22797254.2018.1439343.

Aidaoui, S. (1994) *Ressource en eau et aménagement hydro-agricole dans la région de Biskra (Ziban), Algérie [Water resources and hydro-agricultural development in the Biskra region (Ziban), Algeria]*. PhD Thesis. Nancy: Université Nancy 2. Available at: https://hal.univ-lorraine.fr/tel-01776612 (Accessed: April 04, 2018).

Andrade Foronda, D. and Colinet, G. (2023) "Prediction of soil salinity/sodicity and salt-affected soil classes from soluble salt ions using machine learning algorithms," *Soil Systems*, 7(2), 47. Available at: https://doi.org/10.3390/soilsystems7020047.

Anne, P. (1945) "Sur le dosage rapide du carbone organique des sols [On rapid soil organic carbon determination]," *Annales Agronomiques*, 15, pp. 161–172.

Azizi, P. *et al.* (2011) "Morphological, physico-chemical and clay mineralogy investigation on gypsiferous soils in Southern of Tehran, Iran," *Middle-East Journal of Scientific Research*, 7(2), pp. 153–161. Available at: http://idosi.org/mejsr/mejsr7(2)11/5.pdf (Accessed: December 29, 2011).

Aznar, J.M., Poch, R.M. and Badía, D. (2013) "Soil catena along gypseous woodland in the middle Ebro Basin: Soil properties and micromorphology relationships," *Spanish Journal of Soil Science*, 3(1), pp. 28–44. Available at: https://pdfs.semanticscholar.org/1818/c61fd24384c983cc5daf0a81f60656a2d3e2.pdf?_gl=1*1c1nkqe*_gcl_au*MzI3NzY4MjU0LjE3MTc2NzMzNDM.*_ga*MTU4NTMyMDU0My4xNzA4NDMyNDg5*_ga_H7P4ZT52H5*MTcxODg2NTAzNi44LjEuMTcxODg2NTA0NS41MS4wLjA (Accessed: October 10, 2023).

Bashour, I. and Sayegh, A. (2007) *Methods of analysis for soils of arid and semi-arid regions*. Rome: FAO. Available at: https://msibsri4313.wordpress.com/wp-content/uploads/2013/11/methods-of-soil-analysis-for-arid-semiarid-regions.pdf (Accessed: September 12, 2023).

Belghemmaz, S. (1991) *Contribution à l'étude des sols à accumulations gypseuses de la région de Ain Ben Noui (BISKRA). Essai sur la minéralogie des sols [Contribution to the study of soils with gypsum accumulations in the Ain Ben Noui region (BISKRA). Essay on soil mineralogy]*. BAgr. Thesis. Batna: Univ. of Batna.

Belghemmaz, S. *et al.* (2018) "Assesment of land degradation related to groundwater irrigation of oasis environments. Case study: The Zibans (Biskra), Algeria," *EMCEI 2017. Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions. Technology & Innovation. Proceedings of Euro-Mediterranean Conference for Environmental Integration (EMCEI-1)*, Sousse, Tunisia 22–25 Nov 2017. Cham: Springer, pp. 1289–1290. Available at: https://doi.org/10.1007/978-3-319-70548-4_378.

Bensaid, R. (1999) "Les sols à accumulation gypso-calcaires de la région de Ain Ben Noui (Biskra) [Soils with gypsocalcareous accumulation in the Ain Ben Noui region (Biskra)]," *Annales de l'Institut National Agronomique El Harrach*, 20(1–2), pp. 1–8.

Benziouche, S. and Chehat, F. (2010) "La conduite du palmier dattier dans les palmeraies des Ziban. (Algérie). Quelques éléments d'analyse [The management of date palms in the Ziban palm groves (Algeria). Some elements of analysis]," *European Journal of Scientific Research*, 42(4), pp. 644–660. Available at: https://

www.doc-developpement-durable.org/file/Culture/Arbres-Fruitiers/FICHES_ARBRES/Palmier-dattier/La%20Conduite%20du%20Palmier%20Dattier%20Dans%20les%20Palmeraies_Algerie.pdf (Accessed: June 20, 2010).

Benziouche, S.E. (2017) "L'agriculture biologique, un outil de développement de la filière dattes dans la région des Ziban en Algérie [Organic farming, a tool for developing the date sector in Algeria's Ziban region]," *Cahiers Agricultures*, 26(3), 35008. Available at: https://doi.org/10.1051/cagri/2017025.

Bessaoud, O. *et al.* (2019) *Rapport de synthèse sur l'agriculture en Algérie (Rapport de recherche) [Summary report on agriculture in Algeria (Research report)]*. CIHEAM-IAMM, ffhal-02137632ff. Available at: https://hal.science/hal-02137632/document (Accessed: January 15, 2019).

Bockheim, J.G. *et al.* (2014) "Soil-forming factors and soil taxonomy," *Geoderma*, 226–227, pp. 231–237. Available at: https://doi.org/10.1016/j.geoderma.2014.02.016.

Boyadgiev, T.G. and Verheye, W.H. (1996) "Contribution to a utilitarian classification of gypsum in soils," *Geoderma*, 74, pp. 321–338. Available at: https://doi.org/10.1016/S0016-7061(96)00074-2.

Canton, Y. *et al.* (1996) "Relationships between pedogenesis stages and hydropedological properties on gypsiferous mudstone in the Tabernas desert (SE Spain)," in *Proceedings of the International Symposium on soil with gypsum*, Lleida, Catalonia, Spain 15–21 Sep 1996.

Cherlet, M. *et al.* (eds.) (2018) *World atlas of desertification*. 3rd edn. Luxembourg: Publications Office of the European Union. Available at: https://doi.org/10.2760/9205.

Coque, R. (1964) "A propos des croûtes gypseuses de la Tunisie méridionale [About gypseous crusts in southern Tunisia]," *Annales de Géographie*, 73, 395, pp. 82–86. Available at: https://www.persee.fr/doc/geo_0003-4010_1964_num_73_395_16583 (Accessed: October 10, 2023).

Driessen, P. and Deckers, J. (eds.) (2001) "Lecture notes on the major soils of the world," *World Soil Resources Reports*, 94. Available at: http://www.fao.org/3/a-y1899e.pdf.

Dubost, D. (1986) "Nouvelles perspectives agricoles du Sahara algérien [New agricultural prospects for the Algerian Sahara]," *Revue de l'Occident musulman et de la Méditerranée*, 41–42, *Désert et montagne au Maghreb*, pp. 339–356. Available at: https://doi.org/10.3406/remmm.1986.2466.

Dubost, D. and Larbi-Youcef, Y. (1998) "Mutations agricoles dans les oasis algériennes: l'exemple des Ziban [Agricultural changes in Algerian oases: the example of the Ziban]," *Science et changements planétaires / Sécheresse*, 9(2), pp. 103–110. Available at: https://www.jle.com/fr/revues/sec/e-docs/mutations_agricoles_-dans_les_oasis_algeriennes_lexemple_des_ziban_272879/article.phtml (Accessed: August 10, 1998).

Fernández-Cirelli, A. *et al.* (2009) "Environmental effects of irrigation in arid and semiarid regions. Review," *Chilean Journal of Agricultural Research*, 69 (Suppl. 1), pp. 27–40. Available at: https://www.scielo.cl/pdf/chiljar/v69s1/AT04.pdf (Accessed: December 29, 2009).

Finstad, K., Pfeiffer M. and Amundson, R. (2014) "Hyperarid soils and the Soil Taxonomy," *Soil Science Society of America Journal*, 78 (6), pp. 1845–1851. Available at: https://doi.org/10.2136/sssaj2014.06.0247.

Gouskov, N. (1964) "Notice explicative de la carte géologique de Biskra au 1/200000 [Explanatory note for the 1/200000 geological map of Biskra]," *Publication de la série géologique, Algérie*. Alger: Service Géologique de l'Algérie.

Gumuzzio, J. and Casas, J. (1988) "Accumulations of soluble salts and gypsum in soils of the Central Region, Spain," *Cahiers – ORSTOM. Ser. Pédologie,* 24 (3), pp. 215–226.

Hadj Kouider, M., Eddine Nezli, I. and Belhadj, H.-A. (2017) "The use of spectral responses of surface in the discrimination of soils surface by remote sensing," *Energy Procedia*, 119, pp. 622–631. Available at: https://doi.org/10.1016/j.egypro.2017.07.088.

Halitim, A. (1988) *Sols des régions arides d'Algérie [Soils of arid regions in Algeria]*. Alger: OPU.

Halitim, A. and Robert, M. (1987) "Interaction du gypse avec les autres constituants du sol, analyse microscopique de sols gypseux en zone aride (Algérie) et études expérimentales [Interaction of gypsum with other soil constituents, microscopic analysis of gypsum soils in arid zones (Algeria) and experimental studies]," in N. Fedoroff *et al.* (eds.) *Soil micro morphology. Actes de la VIIe Réunion Internationale de Micromorphologie Des Sols*, Paris, Jun 1985. Paris: AFES, pp. 179–186.

Hannachi, N. *et al.* (2015) "Effects of cultivation on chemical and biochemical properties of dryland soils from southern Tunisia," *Agriculture, Ecosystems & Environment*, 199, pp. 249–260. Available at: https://doi.org/10.1016/J.AGEE.2014.09.009.

Haouchine A. (2010) *Hydrogéologie en zone semi-aride et aride: region de Biskra [Hydrogeology in semi-arid and arid zones: Biskra region]*. PhD Thesis. Alger: USTHB.

Hartemink, A.E. (2015) "The use of soil classification in journal papers between 1975 and 2014," *Geoderma Regional*, 5, pp. 127–139. Available at: https://doi.org/10.1016/j.geodrs.2015.05.002.

Hashemi, S.S., Baghernejad, M. and Khademi, H. (2011) "Micromorphology of gypsum crystals in Southern Iranian soils under different moisture regimes," *Journal of Agricultural Science and Technology*, 13, pp. 273–288.

Herrero, J. and Boixadera, J. (2002) "Gypsic soils," in *Encyclopedia of soil science*, pp. 635–639.

IUSS Working Group WRB (2022) *World reference base for soil resources. International soil classification system for naming soils and creating legends for soil maps*. 4th edn. Vienna, Austria: International Union of Soil Sciences. Last updated: 18 December 2022. Available at: https://www.isric.org/sites/default/files/WRB_fourth_edition_2022-12-18.pdf (Accessed: October 10, 2023).

Karakouzian, M. *et al.* (1996) "Measurements of soluble salt contents of soils from arid and semi-arid regions," *Geotechnical Testing Journal*, 19(4), pp. 364–372.

Keesstra, S.D. *et al.* (2016) "The significance of soils and soil science towards realization of the United Nations sustainable development goals," *Soil*, 2, pp. 112–128. Available at: https://doi.org/10.5194/soil-2-111-2016.

Kopittke, P.M. *et al.* (2019) "Soil and the intensification of agriculture for global food security," *Environment International*, 132, 105078. Available at: https://doi.org/10.1016/j.envint.2019.105078.

Lamqadem, A.A., Afrasinei, G.M. and Saber, H. (2019) "Analysis of Landsat-derived multitemporal vegetation cover to understand drivers of oasis agroecosystems change," *Journal of Applied Remote Sensing*, 13(1), 014517. Available at: https://doi.org/10.1117/1.JRS.13.014517.

Lorenz, K., Lal, R. and Ehlers, K. (2019) "Soil organic carbon stock as an indicator for monitoring land and soil degradation in relation to United Nations' sustainable development goals," *Land Degradation and Development*, 30, pp. 824–838. Available at: https://doi.org/10.1002/ldr.3270.

Mathieu, C. and Pieltain, F. (2003) *Analyse chimique des sols: méthodes choisies [Soil chemical analysis: Selected methods]*. Paris: Tec et Doc. Lavoisier.

McCauley, A., Jones, C. and Olson-Rutz, K. (2017) "Soil pH and organic matter," *Nutrient Management Module*, 8. Available at: https://store.msuextension.org/publications/AgandNaturalResources/4449-8.pdf (Accessed: October 10, 2023).

Mihi, A., Tarai, N. and Chenchouni, H. (2017) "Can palm date plantations and oasification be used as a proxy to fight sustainably against desertification and sand encroachment in hot drylands?," *Ecological Indicators*, 105, pp. 365–375. Available at: https://doi.org/10.1016/j.ecolind.2017.11.027.

Moreno-Jiménez, E. *et al.* (2019) "Aridity and reduced soil micronutrient availability in global drylands," *Nature Sustainability*, 2(5), pp. 371–377. Available at: https://doi.org/10.1038/s41893-019-0262-x.

Moreno-Jiménez, E. *et al.* (2022) "Aridity and geochemical drivers of soil micronutrient and contaminant availability in European drylands," *European Journal of Soil Science*, 73, e13163, pp. 1–12. Available at: https://doi.org/10.1111/ejss.13163.

Moret-Fernandez, D. *et al.* (2021) "Livestock grazing effect on the hydraulic properties of gypseous soils in a Mediterranean region," *Catena*, 207, 105697. Available at: https://doi.org/10.1016/j.catena.2021.105697.

Mortimore, M. *et al.* (2009) *Dryland opportunities: A new paradigm for people, ecosystems and development*. Gland, Switzerland: IUCN, London, UK IIED, Nairobi, Kenya: UNDP/DDC.

Munns, R. and Tester, M. (2008) "Mechanisms of salinity tolerance," *Annual Review of Plant Plant Biology*, 59, pp. 651–681. Available at: https://doi.org/10.1146/annurev.arplant.59.032607.092911.

Munsell Color Company (2014) *Munsell Color System. Color Matching from Munsell Color Company*. [Color chart].

Naorem, A. *et al.* (2023) "Soil constraints in an arid environment – Challenges, prospects, and implications," *Agronomy*, 13, 220. Available at: https://doi.org/10.3390/agronomy13010220.

Navarro-Perea, M. *et al.* (2022) "Plant-soil interactions in response to grazing intensity in a semi-arid ecosystem from NE Spain," *Arid Land Research and Management*, 37(2), pp. 184–196. Available at: https://doi.org/10.1080/15324982.2022.2119901.

Nedjimi, B. (2012) "Seasonal variation in productivity, water relations and ion contents of *Atriplex halimus* spp. *Schweinfurthii* grown in Chott Zehrez wetland, Algeria," *Journal of the Saudi Society of Agricultural Sciences*, 11(1), pp. 43–49. Available at: https://doi.org/10.1016/J.JSSAS.2011.08.002.

Nordt, L.C. *et al.* (2011) "Classification of soils (Entisols)," in M.E. Sumner (ed.) *Handbook of soil sciences: Properties and processes*. Boca Raton, FL: CRC Press, pp. 33.49–33.62.

Omar, S.A.S. and Shahid, S.A. (2013) "Reconnaissance soil survey for the State of Kuwait," in S.A. Shahid *et al.* (eds.) *Developments in soil classification, land use planning and policy implications: Innovative thinking of soil inventory for land use planning and management of land resources*. Dordrecht: Springer. Available at: https://doi.org/10.1007/978-94-007-5332-7_3.

Pashaei, L. and Manafi, Sh. (2021) "Characterization of gypsiferous soils in the north of Urmia, Iran," *Desert*, 26(1), pp. 1–15. Available at: https://doi.org/10.22059/jdesert.2019.279895.1006714.

Pouget, M. (1968) "Contribution à l'étude des croûtes et encroûtements gypseux de nappe dans le Sud-Tunisien [Contribution to the study of gypsiferous nappe encrustations and crusts in south Tunisia]," *Cahiers – ORSTOM. Ser. Pédologie*, 6(3–4). Available at: https://horizon.documentation.ird.fr/exl-doc/pleins_textes/cahiers/PTP/18536.PDF (Accessed: October 10, 2023).

Pouget, M. (1980) "Les relations sol-végétation dans les steppes sud Algéroises [Soil-vegetation relationships in the southern Algerian steppes]," *Travaux et documents de l'ORSTOM*, 116. Paris: Service des Publications ORSTOM. Available at: https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers07/00344.pdf (Accessed: October 10, 2023).

Prăvălie, R. (2016) "Drylands extent and environmental issues. A global approach," *Earth-Science Reviews*, 161, pp. 259–278. Available at: https://doi.org/10.1016/j.earscirev.2016.08.003.

Ramdane, M. (2001) "Agro-pedological studies in Algeria," in P.Z. Druli *et al.* (eds.) *Soil resources of Southern and Eastern Mediterranean countries. Options Méditerranéennes: Série B. Etudes et Recherches*, 34. Bari: CIHEAM, pp. 91–100.

Rasooli, N. *et al.* (2021) "Capability of Soil Taxonomy (2014) compared to updated WRB (2015) in describing Lut Desert soils," *Desert*, 26(2), pp. 219–235. Available at: https://doi.org/10.22059/jdesert.2021.318248.1006804.

Rechachi, M.Z. *et al.* (2021) "Impact of the use of irrigation water on soil salinization: case of the palm grove of Bordj Benazouz BBA-Biskra (Ziban oasis, south-eastern Algeria)," *PONTE International Journal of Sciences and Research*, 77(1/1), pp. 1–22. Available at: https://doi.org/10.21506/j.ponte.2021.1.1.

Rengasamy, P. (2002) "Transient salinity and subsoil constraints to dryland farming Australian sodic soils: an overview," *Australian Journal of Experimental Agriculture*, 42, pp. 351–361. Available at: https://doi.org/10.1071/EA01111.

Roquero, E.G.-C. and Perez Arias, J. (1996) "Influence of slope degree and orientation on geomorphological and pedological differences on gypsiferous soils from Miocene formations in central Spain," in R.M. Poch (eds.) *Proceedings of the International Symposium on soil with gypsum*. Lleida, Catalonia, Spain, 15–21 September 1996. Lleida: University of Lleida, Spain. Available at: https://www.researchgate.net/publication/349163968_Proceedings_of_the_International_Symposium_on_Soils_with_Gypsum_15-21_september_1996 (Accessed: October 10, 2023).

Salehi, M.H. (2018) "Challenges of Soil Taxonomy and WRB in classifying soils: Some examples from Iranian soils," *Bulletin of Geography. Physical Geography Series*, 14, pp. 63–70. Available at: http://dx.doi.org/10.2478/bgeo-2018-0005.

Shahid, A.S., Zaman, M. and Heng, L. (2018) "Salinity and sodicity adaptation and mitigation options" in *Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques*. Cham: Springer. Available at: https://doi.org/10.1007/978-3-319-96190-3_3.

Soil Survey Staff (2014) "Soil survey field and laboratory methods manual," *Soil Survey Investigations Report*, 51, *Version* 2.0. US Department of Agriculture, Natural Resources Conservation Service.

Toomanian, N., Jalalian, A. and Eghbal, M.K. (2003) "Application of the WRB (FAO) and US Taxonomy Systems to Gypsiferous Soils in North west Isfahan, Iran," *Journal of Agricultural Science and Technology*, 5, pp. 51–66. Available at: http://jast.modares.ac.ir/article-23-10104-en.html (Accessed: January 31, 2003).

USDA (1999) *Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys*. 2nd edn. Washington, D.C.: United States Department of Agriculture. Available at: https://www.nrcs.usda.gov/sites/default/files/2022-06/Soil%20Taxonomy.pdf (Accessed: October 10, 2023).

USDA (2014) *Keys to soil taxonomy*. 12th edn. Washington, D.C.: United States Department of Agriculture. Available at: https://ethz.ch/content/dam/ethz/special-interest/usys/ias/grassland-sciences-dam/documents/Education/Graslandsysteme/2014_USDA_Keys_to_Soil_Taxonomy.pdf (Accessed: October 10, 2023).

Vieillefon, J. (1979) "Contribution à l'amélioration de l'étude analytique des sols gypseux [Contribution to improving the analytical study of gypsiferous soils]," *Cahiers ORSTOM, Sér. Pedologie*, 17(3), pp. 195–223.

Visconti, F. and Paz de, J. (2012) "Soil, water and crop management for agricultural profitability and natural resources protection in salt-threatened irrigated lands," in M. Kumar (ed.) *Problems, perspectives and challenges of agricultural water management*. IntechOpen. Available at: https://doi.org/10.5772/29720.

Yaalon, D.H. (1995) "Soils we classify: Essay review of recent publications on Soil Taxonomy," *Catena*, 24, pp. 233–241. Available at: https://doi.org/10.1016/0341-8162(95)00036-1.

Zayed, A.M.A. *et al.* (2023) "A pedological study attempting to combine Soil Taxonomy and WRB classification systems," *Journal of Water and Land Development*, 57, pp. 197–203. Available at: https://doi.org/10.24425/jwld.2023.145350.