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), CaCO3, gypsum, and soil texture. Oasis soils are dominated by gypsum and are all affected by salinity. The rates of OM and CaCO3 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 and 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-economic implications are expected to grow (Moreno-Jiménez...
et al., 2019). Dryland areas are habitat to more than a third of the world’s population (Pravalle, 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), Halitlim and Robert (1987), Halitlim (1988), Nedjimi (2012), and Hannachi et al. (2015). The Ziban oasis environment (ZOE) is degrading in many ways, as stated by Aidaoui (1994), Benzioiuche and Chehat (2010), Afrasinei et al. (2017a), Belghemmaz et al. (2018), and Abdelbaheid, Rechachi and Halitlim (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 AI = 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, Laghrouz, 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 (Salsoa vermiculata, Tamariix 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’lli (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

<table>
<thead>
<tr>
<th>Profile/Site</th>
<th>Coordinates and altitude (Alt.)</th>
<th>Main features described (land use, soil morphology, structure, erosion, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Ourlal 1</td>
<td>34°39′03.76″N; 5°29′37.85″E Alt.: 130 m</td>
<td>recent plant in holes; young date palms; relief: glacial and topography with low slope; compact crust of limestone in the subsoil horizons (from 30 to 120 cm)</td>
</tr>
<tr>
<td>P2 Ourlal 2</td>
<td>34°39′35.36″N; 5°32′59.37″E Alt.: 114 m</td>
<td>new plantations; relatively compact horizons; degraded structure (swollen structure or pseudo-sand); natural vegetation: <em>Salsola</em>, <em>Atriplex</em>, and <em>Tamarix</em>; relief with gentle slope; presence of limestone crust</td>
</tr>
<tr>
<td>P3 Mlli 1</td>
<td>34°41′05.44″N; 5°37′31.11″E Alt.: 92 m</td>
<td>groundwater level around 8–10 m; &quot;Deb Deb&quot; 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</td>
</tr>
<tr>
<td>P4 Mlli 2</td>
<td>34°40′45.06″N; 5°37′28.12″E Alt.: 72 m</td>
<td>very well-developed palm grove (intercropping: associated with olive and palm trees); absence of gypsum crust; limestone compact crust in the underlying horizons; sand aeolian accumulation</td>
</tr>
<tr>
<td>P5 Oumache</td>
<td>34°42′25.98″N; 5°41′00.86″E Alt.: 81 m</td>
<td>water table near the soil surface; abundant salt efflorescences; moist soil surface; death of halophyte species and <em>Tamarix</em> trees</td>
</tr>
<tr>
<td>P6 North Benthious</td>
<td>34°39′32.01″N; 5°28′52.99″E Alt.: 132 m</td>
<td>oasis site with palm and fig trees; soil covered by wind sands; <em>Tamarix</em> trees beside the oasis; absence of gypsum crust; good development of palm and understory crops</td>
</tr>
<tr>
<td>P7 South east Tolga</td>
<td>34°40′39.67″N; 5°26′48.04″E Alt.: 141 m</td>
<td>oasis site consisting of a young plantation of palm trees; &quot;Deb Deb&quot; 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</td>
</tr>
<tr>
<td>P8 South of El Hadjeb</td>
<td>34°45′29.12″N; 5°31′20.51″E Alt.: 185 m</td>
<td>located 5–6 km west of El Hadjeb; within a well-developed palm grove; salt efflorescences covering the soil surface; presence of crust of &quot;Deb Deb&quot;</td>
</tr>
<tr>
<td>P9 El Hadjeb</td>
<td>34°47′38″N; 5°36′33″E Alt.: 175 m</td>
<td>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</td>
</tr>
<tr>
<td>P10 Ain Ben Noui (North ITDAS)</td>
<td>34°47′51″N; 5°37′09.89″E Alt.: 141 m</td>
<td>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</td>
</tr>
</tbody>
</table>

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 CaCO₃ 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 (Ca²⁺, 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 (PPF7 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
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.

Concerning salinity, we note that EC can also vary and range from 2.08 (P8H3) to 30.00 dS∙m⁻¹ for P5H1. It should be noted that low salinity oases are characterised by generally very low CaCO₃ 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⁺, Ca²⁺, Mg²⁺, HCO₃⁻, Cl⁻, CO₃²⁻, and SO₄²⁻, 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.

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

<table>
<thead>
<tr>
<th>Pedon (P)</th>
<th>Horizon (H)</th>
<th>Soil chemical analyses</th>
<th>Soil texture and organic matter (OM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>depth (cm)</td>
<td>pH (water)</td>
</tr>
<tr>
<td>P1</td>
<td>H1</td>
<td>0–30</td>
<td>7.67</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>7.77</td>
</tr>
<tr>
<td>P2</td>
<td>H1</td>
<td>0–30</td>
<td>7.77</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>8.00</td>
</tr>
<tr>
<td></td>
<td>H3</td>
<td>60–120</td>
<td>7.475</td>
</tr>
<tr>
<td>P3</td>
<td>H1</td>
<td>0–30</td>
<td>7.58</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>7.72</td>
</tr>
<tr>
<td>P4</td>
<td>H1</td>
<td>0–30</td>
<td>7.54</td>
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<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>7.51</td>
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<tr>
<td>P5</td>
<td>H1</td>
<td>0–30</td>
<td>8.20</td>
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<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>8.13</td>
</tr>
<tr>
<td></td>
<td>H3</td>
<td>60–120</td>
<td>8.41</td>
</tr>
<tr>
<td>P6</td>
<td>H1</td>
<td>0–30</td>
<td>7.91</td>
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<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>7.76</td>
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<td>H3</td>
<td>60–120</td>
<td>7.60</td>
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<tr>
<td>P7</td>
<td>H1</td>
<td>0–30</td>
<td>8.56</td>
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<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>8.46</td>
</tr>
<tr>
<td></td>
<td>H3</td>
<td>60–120</td>
<td>8.05</td>
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<tr>
<td>P8</td>
<td>H1</td>
<td>0–30</td>
<td>7.70</td>
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<td></td>
<td>H2</td>
<td>30–60</td>
<td>7.60</td>
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<tr>
<td></td>
<td>H3</td>
<td>60–120</td>
<td>7.59</td>
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<tr>
<td>P9</td>
<td>H1</td>
<td>0–30</td>
<td>7.52</td>
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<td></td>
<td>H2</td>
<td>0–60</td>
<td>7.55</td>
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<tr>
<td></td>
<td>H3</td>
<td>60–120</td>
<td>7.55</td>
</tr>
<tr>
<td>P10</td>
<td>H1</td>
<td>0–30</td>
<td>7.50</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>30–60</td>
<td>7.82</td>
</tr>
<tr>
<td></td>
<td>H3</td>
<td>60–120</td>
<td>7.71</td>
</tr>
</tbody>
</table>

Explanations: EC = electrical conductivity, SL = sandy loam, L = loam, SCI = sandy clay, SCIL = sandy clay loam.
Source: own study.
**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, gypsic soils are generally found in flat to hilly lands or depressions, as noted by Boyadgiev and Verheye (1996).

Precipitation and dissolution of gypsic 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 Azizi et al. (2011), these dynamics imply that gypsum is leached during wet periods and rises by capillarity during dry periods. According to these authors, CaSO₄∙2H₂O 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, MgCl₂) and even MgSO₄ are very mobile in soil. The other salts, such as gypsum, are either slightly soluble or little soluble, e.g. CaCO₃ (Karakuozian et al., 1996). Guzzullo 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 gypsum 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 Nouri, 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 CaCO₃ 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...
Typology characterisation and monitoring of arid soils in an agroecosystem environment: Case of Ziban oasis, Algeria

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 toposquence 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: Gyspelic Solonchaks (hypersalic) in P2 and P5, and Yermic Gyspelic 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>
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<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) 7/5 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 (se) 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 (se)</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 (Cyj)</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&lt;40%)</td>
<td>gypsic (gy)</td>
<td>8/2 10YR (H1) 7/3 10YR (H2)</td>
</tr>
<tr>
<td>P9</td>
<td>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>ochric epipedon predominance of mineral material (particularly sand) and absence of distinct soil-genetic horizons</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>
</tbody>
</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 (protopsolic) 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 CaCO₃, 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 Boixadara (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). Arenosols are represented by two main soil types, i.e. Gypsicric and Yermic (Endosalic, protogypsic) which was identified in P9 and has a maximum salinity (15.39 dS·m⁻¹) at depth; Gypsicric and Yermic Arenosols (protosalic) in P10, which has low salinity in the lower horizons and moderate salinity (5.33 dS·cm⁻¹) at the surface. These particular soil types were found on the Djebel Bouhazal 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 gyspic, petrogypsic, and salic horizons. Although almost half of the soil samples contain from 9.78% to 24.35% CaCO₃, 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 Gypsis 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 Gypsis: Typic Haplogypsis 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 Haplogypsis, 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·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 gyspic 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 gyspic and petrogyspic horizons were formed by the intrusion of gypsum 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 Psammments) (Bockheim et al., 2014).

Only the SO of Psammments 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 CaCO₃ 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 UAE.

**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 potrogypsic 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 Gypsis identified in the research area do not present a calcic horizon above the gypsic or potrogypsic horizon.

Furthermore, Moret-Fernandez et al. (2021) revealed the presence of Typic Haygypsids and Gypsic Haplosalids in semiarid climate in NE Spain. These gypsisiferous 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 Haygypsids observed in the WZ (P1, P2, P3, P4, P6 and P) are almost similar to those described. However, the Gypsis 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 gyspiferous 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 gyspiferous soils. However, according to Sarshogh (2010), as cited in Rasooli et al. (2021, p. 220), who studied the soils in the Babadehair 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](https://example.com/f2)

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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).

**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 depending on the colour and lightness, grain size, humidity and nature of the mineral soil surface.

**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 topo-sequences was possible. The predominant soil types in the WRB (RSGs) were Gypsisols, Solonchaks, and Arenosols. The Gypsis, Salis, and Psammox were suborders of the ST. Gypsisicous 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, understoreys 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


Vieillefon, J. (1979) “Contribution à l’amélioration de l’étude analytique des sols gypseux [Contribution to improving the

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