EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(8), 155–171
https://doi.org/10.12912/27197050/171528
ISSN 2719–7050, License CC-BY 4.0

Received: 2023.07.19
Accepted: 2023.09.25
Published: 2023.10.13

Physico-Chemical Characterization and Quality of Agricultural Soils in the Zaër Region (Morocco)

Mariyam El Omari[1*], Nadia Aziane[2], Mohammed Amine Zerdeb[1], Basma Naoui[1], Abdelali El Mekkaoui[1], Nouhaila Akhlidej[1], Jamal Oubbih[1], Saïd Chakiri[1], Omar Amahmid[1,3,] Abdelmjid Zouahri[4]

[1] Laboratory of Geosciences, Department of Geology, Faculty of Sciences, Ibn Tofaïl University, Kenitra 14000, Morocco

[2] Laboratory of Organic Chemistry, Catalysis and Environment, Department of Chemistry, Faculty of Sciences, Ibn Tofail University, Kenitra 14000, Morocco

[3] Polydisciplinary Laboratory for Research in Didactic, Education and Training, Department of Life and Earth Sciences, Regional Centre for Education and Training Professions. CRMEF Marrakech-Safi, Ibn Rochd, Marrakech 40000, Morocco

[4] National Institute of Agricultural Research, Rabat 10090, Morocco

* Corresponding author's e-mail: elomarimeryam@gmail.com

ABSTRACT

This qualitative study of the soils of the Zaër region is part of a context of good development, preservation and sustainability of agricultural soils. Its aim is to establish a reference framework for the physico-chemical characteristics of the region's agricultural soils. It was based on a spring sampling campaign carried out in 2021. Composite samples taken from thirteen sites with diverse soils were analysed in the laboratory. The soil analysis results were compared with reference values. The soils examined were moderately acidic to moderately alkaline, with low levels of organic matter. Nevertheless, concentrations of exchangeable calcium and magnesium were found to be sufficient, while sodium levels were very low. Furthermore, cation exchange capacity was low in spring, reflecting the soil's high and low nutrient retention capacity respectively. Phosphorus and potassium levels appear to be low. In the light of these results, the use of organic and mineral fertilisers and calcium amendments is strongly recommended to improve agricultural quality and productivity in the region studied.

Keywords: physico-chemical analyses, qualitative study, agricultural soil, Zaër region, Morocco.

INTRODUCTION

Soil is one of the essential natural resource, providing the main mineral elements for plant development and agricultural production [Haritha et al, 2022]. It is a living entity and not just a substrate in which plants grow. Soil is the top layer of the earth's crust, made up of inorganic and organic matter [Schoonover and Crim, 2015).

Agriculture refers to the ability to raise plants from the soil and is one of the most economic factors for human beings. But the concentrated use of agrochemicals and their residues can lead to soil degradation, which includes negative effects, particularly in vegetable and market garden production [Fotio et al., 2004]. Soil fertility is a key factor in determining plant growth. It depends on organic and inorganic matter (N, P, K), micronutrients and water. Chemical soil fertility is the requirement for nutrient inputs, the lack of which is the main factor in soil degradation [Hartemink, 2010].

The Zaër region benefits from a privileged geographical location, a satisfactory transport infrastructure, a favourable physical environment (climate, soil and water resources), and a large useful agricultural area (UAA) [Monographie, 2015]. This potential gives it a considerable place in regional and national agricultural production. The region is considered to be a major agricultural centre par excellence, known nationally for its high potential in cereal and pulse crops. The growth and development of this agriculture has led to an intensification in the use of agricultural land, sometimes in an irrational way.

On the other hand, the region's agricultural land is under heavy pressure from erosion, overgrazing, inappropriate use of tools and, above all, the drop in rainfall over the last decade, given that the region's agriculture (cereals and pulses) is based on the bour. This has an impact on the functional properties and quality of the soil [Saber and Mrabet, 2002]. As a result, this study was assessed using a number of physico-chemical indicators.

The main aim of this work is to assess the quality of soils in the Zaër region by characterizing physico-chemical parameters (pH, organic matter, assimilable phosphorus, exchangeable potassium, cation exchange capacity and exchangeable bases).

MATERIALS AND METHODS

Study area

The Zaër region is located in north-west Morocco, 80 km south-east of Rabat, and belongs to the administrative region of Rabat-Salé-Kénitra; it is attached to the province of Khemisset. The area covered by this study lies between latitude 33°30' and 33°45' North and longitude 6°24' and 6°45' West, with altitudes varying between 200 and 500 m. The study region shows great diversity in the landscape and in the genesis and evolution of the geological formations of the thirteen experimental sites (Fig. 1). It is represented by [El Hassani, 1990]:

- Silico-clastic deposits during the Palaeozoic; these Palaeozoic formations, mainly of Visean age, are widely exposed in the northern and western parts of the study area in the Sidi Bettache basin. The Visean land, have very low permeability and are generally made up of sandstones and quartz sandstones traversed by a network of fractures and diaclases acquiring fissure permeability, pelites, shales and fairly localised dolerite veins [Combe et al., 1975];
- Saliferous red clays and impermeable basaltic rocks of Mesozoic (Triassic) age occupy the southern and eastern parts of the region [Combe et al., 1975];
- Marly and carbonated soils of Miocene age made up of calcarenites, lumachelles, yellow biodetritic sands with conglomeratic intercalations and quaternary silts, clays and sands occupy the southern and eastern parts of the region.

The geological formations in the study area have a fairly diverse lithology, ranging in age from Paleozoic schist bedrock to Quaternary surface strata. The region has a Mediterranean climate, with cool, wet winters and dry, hot summers.

Because of its lithological diversity, climatic factors and geological characteristics, the study region has a fairly diverse range of soils (Fig. 2). According to the French classification of soils [CPCS, 1967]:

- Vertisols developed on dolerite basalt and Triassic red clay parent rock, distributed along the wide valleys of the Rommani depression, with sites on calcimagnesic soils;
- Vertisols formed in a semi-arid climate and developed on a parent rock of sandy marl and Miocene calcarenites; they are distributed over the Merchouch plateaux [Mekkaoui et al., 2021];
- Complex soils (alkaline soils); these are a burnished soil and a soil with crude minerals which extend into the Jamaa Moullablad sector and cover only a small area;
- Isohumic soils with traces of poorly developed soils located in the Aïn Sbit sector [Mekkaoui et al., 2021].

Sampling and analysis techniques

The choice and distribution of sampling sites in the study region take into account a number of parameters, including geological and geomorphological contexts and soil diversification, i.e. the nature of the parent rock, as well as topography, slope exposure, soil types, cropping practices and yields, previous cropping, and the homogeneity of the chosen soil. In this study, the sampling campaign was carried out during the spring season of 2021 at thirteen sites (SZ_1, SZ_2, SZ_3, SZ_4, SZ_5, SZ_6, SZ_7, SZ_8, SZ_9, SZ_{10}, SZ_{11}, SZ_{12} and SZ_{13}). To assess water and nutrient retention potential, two samples were taken per site, one at 20 cm and the other at 40 cm (Fig. 3).

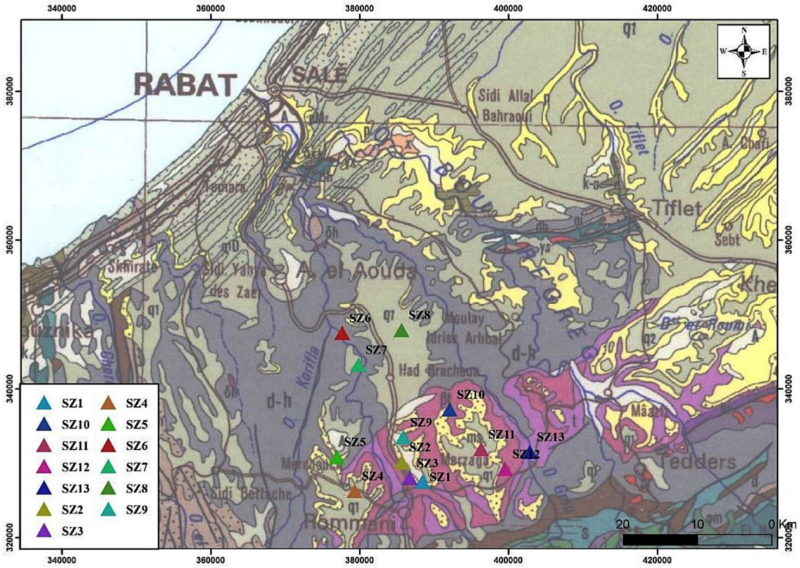

Figure 1. Geological map of the study area

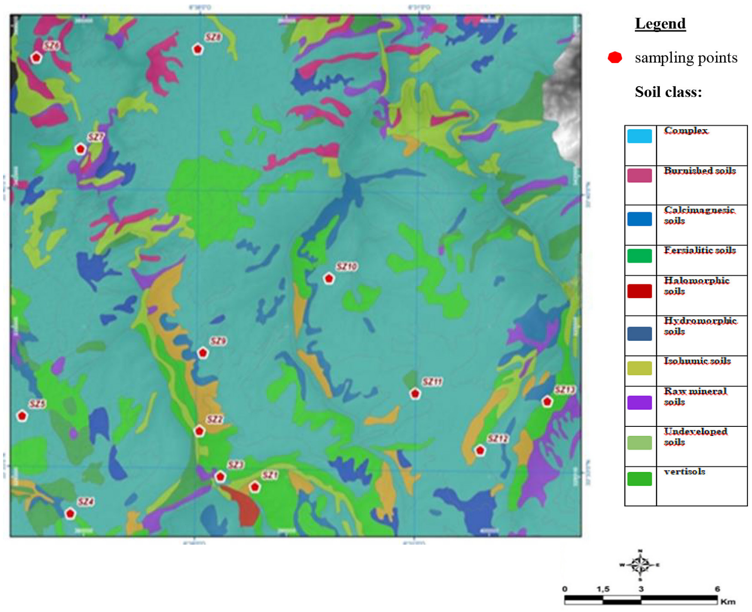

Figure 2. Distribution of different soils in the study area

Samples are taken using topographical and geological maps of the study region; samples are taken using an auger to form a composite sample which is then transported to the laboratory of the National Institute of Agricultural Research in Rabat for air-drying, aggregate reduction and sieving to 2 mm. The sieve is recovered for physico-chemical analysis.

The following parameters were analysed: particle size, pH, electrical conductivity (EC), organic matter (OM), assimilable phosphorus (P_2O_5), exchangeable potassium (K_2O), cation exchange capacity (CEC) and exchangeable cations. The physico-chemical characteristics of the soils studied were determined using the following techniques:

- Granulometry: is carried out using a Robinson pipette, after destruction of organic matter with hydrogen peroxide, total limestone with 1N sodium acetate and dispersion with sodium hexametphosphate [AFNOR, 2003];
- Total limestone: was determined using the Bernard calcimeter, after etching with HCl 6N hydrochloric acid;
- pH water: was measured with a pH meter on a soil/water solution at 1/2.5 [Mathieu and Pieltain, 2003];

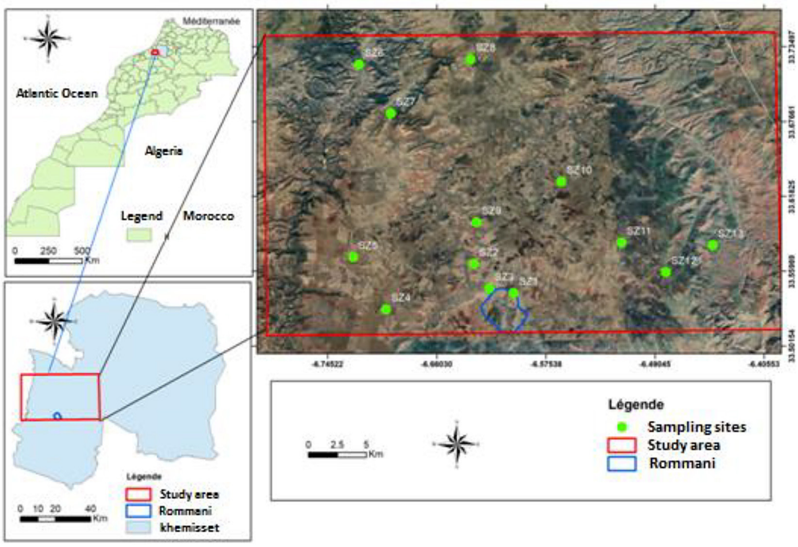

Figure 3. Location of the thirteen study sites in the Zaër region, Morocco

- Electrical conductivity (EC): was measured using an Orion conductivity meter, model 162. Measurements were taken on soil solutions of the 1/5 saturated paste extract; it is expressed in mS/cm at 25°C [U.S.S.L, 1954];
- Organic matter (OM): is quantified by the Walkley-Black method, this consists of cold oxidation of the organic fraction of carbon by potassium dichromate in an acid medium and titration by Mohr's salt. The percentage of organic matter is calculated using the following formula: OM% = C% × 1.724 [Walkley and Black, 1934] ;
- Assimilable phosphorus (P_2O_5): was determined by the OLSEN method in which extraction is carried out using sodium hydrogen carbonate at pH 8.5; this method is based on the formation and reduction of a complex of ortho-phosphoric acid and molybdic acid. The phosphorus content is read using a UV Visible spectrophotometer-model JENWAY 6405 at a wavelength of 825 nm. The result is expressed in ppm [Olsen, 1954];
- Exchangeable potassium and sodium (K_2O and NaO): extraction is carried out using CH3COONH4 1N ammonium acetate at pH 7. K_2O and Na^+ levels were determined using a CL 378 flame photometer. Results are expressed in ppm [Van Rast et al., 1999];
- Exchangeable bases (CaO and MgO): are determined using 5N NaOH solution, 1/3 triethanolamine solution and 5% KCN potassium cyanide solution; Na^+ is determined using 1 N CH3COONH4 ammonium acetate at pH 7 [Bower et al., 1952];
- Cation exchange capacity (CEC): was determined by the sodium acetate method [Bower et al., 1952].

The standards of interpretation of soil fertility are those used by the Office of Agricultural Development of Gharb (Table 1) [DIAEA /DRHA / SEEN, 2008].

The statistical data processing contains descriptive statistical analysis, Pearson correlation, and multivariate method used is principal component analysis (PCA). This factorial method uses linear links between variables and individuals. It allows for a good graphical representation that serves to facilitate the interpretation of the relationships between variables and observations. These statistical analyses of the data were done with Excel Stat software.

RESULTS AND DISCUSSION

Characterisation of soil physico-chemical parameters

Granulometry of soils

The texture of a soil corresponds to the particle size distribution of its constituents (sands, silts and clays). It affects the physical properties of the soil, in particular drainage, aeration, water retention, root penetration and the ease with which the soil can be worked. It also has an effect on the nutritional status of the soil [Kekane et al., 2015; Tale and Ingole, 2015; Nijimbere et al., 2020].

Table 1. Standards and interpretation of soil fertility indicators [DIAEA /DRHA /SEEN, 2008]

Parameters	Values	Interpretation
pH	< 6	Acidic
	6 – 6,5	Weakly acidic
	6,5 – 7,3	Neutral
	7,3 – 7,8	Weakly basic
	7,8 – 8,5	Moderately basic
	8,5 – 9	Alkaline tendency
	> 9	Very alkaline
CE (dS/m)	< 4	Non saline
	4 – 8	Not very saline
	8 – 16	Saline
	16 – 32	Highly saline
	> 32	Very strongly saline
Organic matter (%)	< 0,7	Very poor
	0,7 – 1,5	Poor
	1,5 – 3	Moderately poor
	3 – 6	Rich
	> 6	Very rich
Available phosphorus P_2O_5 (%)	< 15	Very low
	15 – 30	Low
	30 – 45	Well provided
	45 – 100	High
	> 100	Very high
Exchangeable potassium K_2O (ppm)	< 60	Very low
	60 – 100	Low
	100 – 180	Well provided
	180 – 300	High
	> 300	Very high
Total nitrogen (%)	< 0,1	Low
	0,1 – 0,15	Medium
	> 0,15	High
CEC (Cation exchange capacity) (méq/100g soil)	< 5	5–10
	Very low	Low
S (Sum of exchangeable cations) (méq/100g soil)	< 2	2–5
	Very low	Low
%V=S/T·100 (saturation level)	< 15	15–40
	Very low reserve	Low reserve

The granulometric analysis of the soils studied revealed that most of the soils in our study region are dominated by the silt fraction (SZ_1, SZ_2, SZ_3, SZ_4, SZ_5, SZ_8, SZ_9, SZ_{10} and SZ_{13}), with a percentage of silt that can reach 78% in SZ1. The soils at stations SZ_6, SZ_{11} and SZ12 have a silty-clay and sandy-clay texture respectively, with a clay content of 40% recorded at station SZ_{11}. The texture of soil SZ7 is silty-clayey-sandy, with a sand content of over 50%. The sandy fraction is in second place, followed by the clay fraction (Table 2). A study carried out on soils in the Zaër region shows the dominance of the clay fraction, silt-clay to silty-clay and silty-clay to clay [Mekkaoui et al., 2021].

The representation on the USDA texture triangle shows that the textural class of the soils studied is silty, with 18% clay, 51% silt and 30% sand on average (Fig. 4). These different particle size classes form part of the balanced textures for agriculture. They are well aerated textures, easy to work with, allowing suitable infiltration by roots and good water retention capacity with satisfactory permeability [Kekane et al., 2015].

Total limestone of soils

Total limestone is all the limestone present in the soil in all its forms: insoluble, soluble and exchangeable. Its origin is linked to the alteration of the parent rock and the addition of basic soil improvers (liming). The results of analyses of total limestone in the soils studied show that levels are very low, varying between 0 and 3% (Table 3 and Fig. 5). These are non-calcareous to slightly calcareous soils.

Table 2. Physical constituents of the soils studied

Stations	Depth (cm)	Mineral part			Textural characterization
		Clay, %	Silt, %	Sand, %	
SZ_1	0–20	10	78	12	Silt loam
	20–40	10	76	14	Silt loam
SZ_2	0–20	10	71	18	Silt loam
	20–40	10	72	18	Silt loam
SZ_3	0–20	20	29	51	Loam
	20–40	20	32	48	Loam
SZ_4	0–20	10	38	52	Loam
	20–40	10	49	41	Loam
SZ_5	0–20	10	45	45	Loam
	20–40	10	41	49	Loam
SZ_6	0–20	35	50	15	Silty clay loam
	20–40	35	51	14	Silty clay loam
SZ_7	0–20	20	27	53	Sandy clay loam
	20–40	20	23	58	Sandy clay loam
SZ_8	0–20	20	59	21	Silt loam
	20–40	20	59	21	Silt loam
SZ_9	0–20	10	63	27	Silt loam
	20–40	10	29	62	Sandy loam
SZ_{10}	0–20	15	66	19	Silt loam
	20–40	15	70	15	Silt loam
SZ_{11}	0–20	40	41	19	Silty clay
	20–40	41	44	15	Silty clay
SZ_{12}	0–20	31	52	17	Silty clay loam
	20–40	31	53	17	Silty clay loam
SZ_{13}	0–20	15	77	8	Silt loam
	20–40	15	77	8	Silt loam

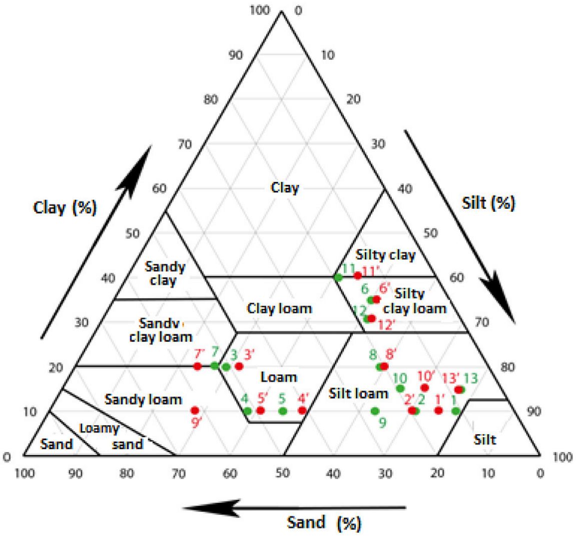

Figure 4. USDA textural triangle for soils in the study area

A slight increase in the level of limestone as a function of depth was observed at sites SZ1 and SZ11, whereas a decrease in this level was observed at sites SZ_2 and SZ_8. This is probably due to vertical leaching of calcium carbonate and farming practices.

These low levels of limestone in the soils studied are certainly due either to the lithological nature of the parent rocks, or to the size of the limestone elements. A low limestone content, and therefore a low calcium (Ca^{2+}) content, has an impact on the physico-chemical balance of the soil, in particular the formation of clay-humus complexes capable of retaining plant nutrient cations on their surface [Baize, 2000].

Equivalent soil humidity

Equivalent moisture or water content is one of the most important properties of soil. Too much or too little water in the soil has consequences not only for nutrient uptake and plant growth, but also for microbiological and soil processes [Labrecque, 2011].

Analysis of the equivalent moisture results reveals that the soils studied have a fairly high percentage of H_2O, varying between 23.03% and 30.4%, particularly in the superficial horizons from 0 to 20 cm (Table 4 and Fig. 6). This moisture content decreases or even disappears in the lower horizons (20–40 cm). This means that the majority of soils are moist, plastic and malleable at the surface.

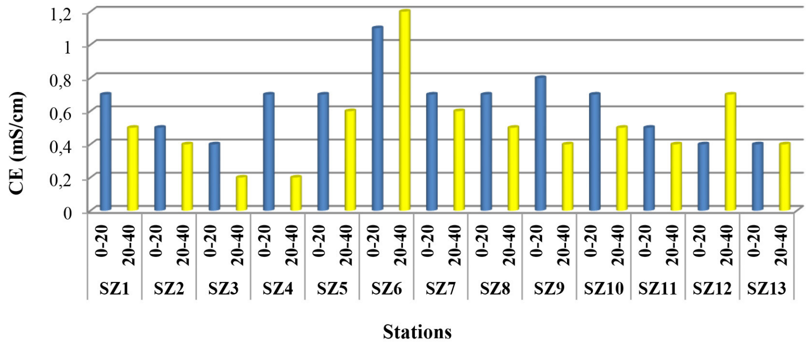

Figure 5. Total limestone content according to the depth of the soils studied

Table 3. Total limestone content of the soils studied

Stations	Depth (cm)	% $CaCO_3$
SZ_1	0–20	0
	20–40	1
SZ_2	0–20	1
	20–40	0
SZ_3	0–20	0
	20–40	0
SZ_4	0–20	0
	20–40	0
SZ_5	0–20	0
	20–40	0
SZ_6	0–20	0
	20–40	0
SZ_7	0–20	0
	20–40	0
SZ_8	0–20	2
	20–40	0
SZ_9	0–20	0
	20–40	0
SZ_{10}	0–20	0
	20–40	0
SZ11	0–20	0
	20–40	2
SZ12	0–20	3
	20–40	3
SZ13	0–20	1
	20–40	1

Table 4. Humidity analysis results for the soils studied

Stations	Depth (cm)	Equivalent humidity (%)
SZ_1	0–20	26.51
	20–40	24.64
SZ_2	0–20	23.03
	20–40	0.00
SZ_3	0–20	26.43
	20–40	0.00
SZ_4	0–20	26.17
	20–40	0.00
SZ_5	0–20	28.35
	20–40	0.00
SZ_6	0–20	26.25
	20–40	0.00
SZ_7	0–20	30.40
	20–40	0.00
SZ_8	0–20	28.96
	20–40	24.24
SZ_9	0–20	25.16
	20–40	0.00
SZ_{10}	0–20	23.90
	20–40	25.77
SZ11	0–20	29.36
	20–40	0.00
SZ12	0–20	26.99
	20–40	0.00
SZ13	0–20	26.12
	20–40	0.00

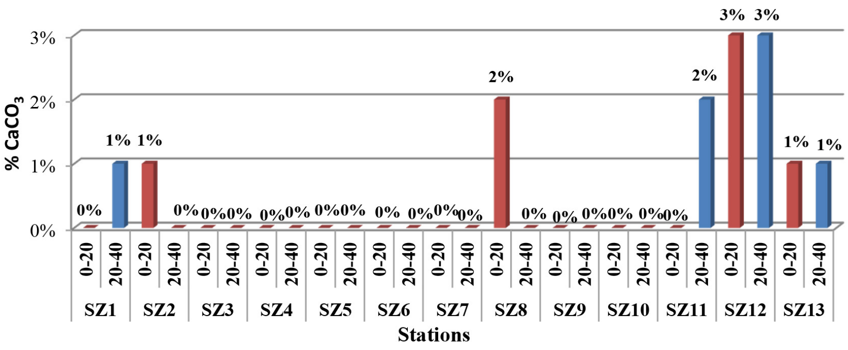

Figure 6. Variations in moisture content with depth at sampling stations

Hydrogen potential of soils

The pH is an indication of the concentration of hydrogen ions (H^+) present in the soil. These ions come from biological reactions of organic matter and root activity [Félix-Faure et al., 2013]. It conditions many of the chemical and microbiological reactions that take place in this compartment and specifically affects nutrient availability, biological life and plant growth [Mulaji et al., 2016]. It is determined by pHwater and pH_{KCl}.

The results of the pH analyses of the soils sampled during the spring season ranged from 5.4 to 8.2, except for SZ_6, which is a moderately acidic soil, meaning that it is moderately alkaline to weakly acidic.

The ΔpH values (= pH_{KCl} – pHwater) are either positive, zero or slightly negative indicating the dominance of variable charge minerals [Nijimbere et al., 2020]. Acidic soils with a ΔpH close to zero appear to contain a low exchangeable Al^{3+} content, which is the case for the following soils: SZ_4 (0–20cm), SZ5 (20–40cm), SZ_6 (20–40cm) and SZ_7 (0–20cm). In the case where the ΔpH is largely negative, which is the case for the stations sampled where the ΔpH varies from -0.9 to -1.2, it is difficult to determine the type of dominant loads (variable loads more than permanent loads). Furthermore, in all cases, the pH (H_2O) is higher than the pH KCl, indicating the presence of negatively charged colloids in the soils studied (Table 5) [Mulaji, 2016].

Electrical conductivity of soils

Soil electrical conductivity is used to determine the concentration of soluble salts in soils, as well as measuring the quantity of ions present in the soil solution. As the concentration of ions increases, so does the electrical conductivity, which helps to measure salinity [Nijimbere, 2020].

The results of the electrical conductivity analyses of all the soils sampled show that site SZ6 has the highest electrical conductivity values of 1.2 ms/cm for the 20–40 cm depth and 1.1 ms/cm for the 0–20 cm depth, while the lowest value of 0.2 ms/cm is represented by sites SZ3 (20–40 cm) and SZ4 (20–40 cm) (Table 6).

In most of the soils studied, salinity is concentrated more at the surface than at depth, with an elemental variance of no more than 0.5 mS/cm from the surface (0–20 cm) to the lower horizon (20–40cm), explained by the absence of leaching of salts from the surface to depth (Fig. 7).

Table 5. pHwater and pH_{KCL} values in the soils studied

Stations	Depth (cm)	pH water	pH Kcl	ΔpH = pH_{KCl} _ pH eau	Soil type
SZ_1	0–20	7,9	6,9	-1	Moderately alkaline
	20–40	8	7	-1	
SZ_2	0–20	8	7,1	-0,9	Moderately alkaline
	20–40	8,1	7,1	-1	
SZ_3	0–20	7,1	6,4	-0,7	Neutral
	20–40	6,8	6,1	-0,7	
SZ_4	0–20	6,5	6	-0,5	Weakly acid
	20–40	6,2	5,2	-1	
SZ_5	0–20	5,4	4,6	-0,8	Moderately acid
	20–40	5,9	5,4	-0,5	
SZ_6	0–20	5,7	5	-0,7	Moderately acid
	20–40	6,4	5,9	-0,5	
SZ_7	0–20	6	5,4	-0,6	Moderately acid
	20–40	5,4	4,7	-0,7	
SZ_8	0–20	7,5	6,8	-0,7	Weakly alkaline
	20–40	7,7	6,9	-0,8	
SZ_9	0–20	7,1	6,4	-0,7	Neutral
	20–40	6,8	5,7	-1,1	
SZ_{10}	0–20	7,9	7	-0,9	Moderately alkaline
	20–40	8	7	-1	
SZ_{11}	0–20	7,9	6,9	-1	Moderately alkaline
	20–40	7,9	6,9	-1	
SZ_{12}	0–20	8	7,2	-0,8	Moderately alkaline
	20–40	8	7,1	_0,9	
SZ_{13}	0–20	8,2	7	-1,2	Moderately alkaline
	20–40	8,2	7	-1,2	

Table 6. Electrical conductivity values for the soils studied

Stations	Depth (cm)	CE (mS/cm)	Class of salinity
SZ_1	0–20	0,7	Not saline
	20–40	0,5	
SZ_2	0–20	0,5	Not saline
	20–40	0,4	
SZ_3	0–20	0,4	Not saline
	20–40	0,2	
SZ_4	0–20	0,7	Not saline
	20–40	0,2	
SZ_5	0–20	0,7	Not saline
	20–40	0,6	
SZ_6	0–20	1,1	Not saline
	20–40	1,2	
SZ_7	0–20	0,7	Not saline
	20–40	0,6	
SZ_8	0–20	0,7	Not saline
	20–40	0,5	
SZ_9	0–20	0,8	Not saline
	20–40	0,4	
SZ_{10}	0–20	0,7	Not saline
	20–40	0,5	
SZ_{11}	0–20	0,5	Not saline
	20–40	0,4	
SZ_{12}	0–20	0,4	Not saline
	20–40	0,7	
SZ_{13}	0–20	0,4	Not saline
	20–40	0,4	

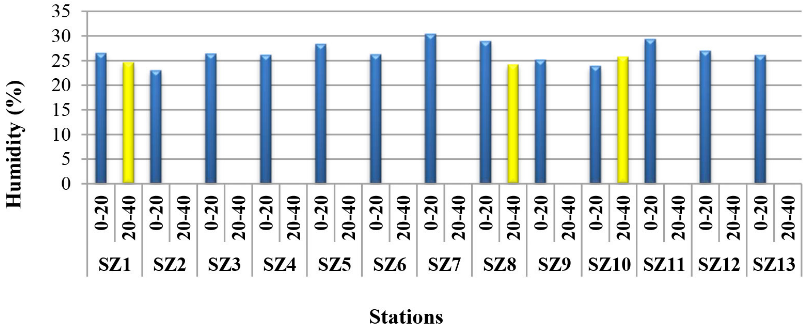

Figure 7. Electrical conductivity of soils as a function of depth during the spring season

Most of the soils in the study region are not very saline; this is due to the management of the leaching of salts in the soils, to the large amounts of rainfall which limit the phenomenon of evaporation. However, the agricultural area of Zaër represents on average 58.6% of the total area of this region, which is mainly located in rain-fed conditions [Benbrahim et al., 2017], i.e. the soils retain their physical characteristics and withstand a long working life, unlike groundwater-irrigated soils, which can lead to changes in physico-chemical properties through an increase in osmotic pressure, which limits the absorption and supply of water by plants and thus the degradation of crops. This phenomenon causes the surface water table to rise, leading to poor drainage control and salinisation of agricultural soils.

Organic matter of soils

Soil organic matter is an important indicator of soil quality [Laudicina, 2015; Parras-Alcantara, 2015] through its contribution to soil stability, increased soil water retention capacity, fixation of mineral elements, and substrate for soil microorganisms [Khodrani et al., 2017].

Analysis of the organic matter results for the soils studied indicates a basic variation in rates from one horizon to another and within the same station. Thus, organic matter levels vary from 0.1% to 1.4% and are high in the superficial level from 0 to 20 cm, as this horizon contains all the organic restitutions (manure, dead leaves, etc.), except at one site where the opposite is found, such as SZ_{13} (0–20 cm) and SZ_{13} (20–40 cm). This is in agreement with the results obtained on the Zaër soils, which show that the organic matter content varies from less than 1% to 3.4% (Table 7).

To remedy the organic matter deficiency, animal organic amendments are recommended to improve the quality of these agricultural soils [El Oumlouki, 2014].

Assimilable phosphorus in soils

Assmilable phosphorus is a major nutrient and mineral element required for plant growth and development; it is present in every living cell [Nijimbere et al., 2021]. It is an essential and obligatory chemical element that is considered an important macronutrient for agricultural productivity [Holford, 1997].

Table 7. Organic matter content of the soils studied

Stations	Depth (cm)	MO (%)	Interpretation
SZ_1	0–20	2,6	Poor
	20–40	2,3	
SZ_2	0–20	2,3	Poor
	20–40	2,2	
SZ_3	0–20	2,6	Poor
	20–40	1,6	Very poor
SZ_4	0–20	2	Poor
	20–40	1,4	Very poor
SZ_5	0–20	2,5	Poor
	20–40	1,9	Very poor
SZ_6	0–20	3,6	Poor
	20–40	2,9	
SZ_7	0–20	2	Very poor
	20–40	1	
SZ_8	0–20	2,9	Poor
	20–40	2,5	
SZ_9	0–20	2,4	Poor
	20–40	1,3	Very poor
SZ_{10}	0–20	3	Poor
	20–40	2,7	
SZ_{11}	0–20	3,3	Poor
	20–40	2,8	
SZ_{12}	0–20	2	Poor
	20–40	2,2	
SZ_{13}	0–20	1,8	Very poor
	20–40	2,3	Poor

The results of the assimilable phosphorus analyses of the soils studied show that average phosphorus levels vary from 1.6 to 210.1 ppm (Table 8, Fig. 8). Station SZ6 has the highest phosphorus content (210.1 ppm). Phosphorus levels are very high during the spring season as a result of the excessive use of phosphorus fertilisers both on the surface and at depth. Another study carried out on Zaër soils shows that the assimilable phosphorus content of the soil varies from 8.4 to 45.4 ppm. It could be linked to the input of phosphate fertilisers, which is related to the category of farmers. The low amount of phosphorus in the soil has an impact on root development, photosynthesis and therefore on crop production potential [Benbrahim et al., 2017].

Exchangeable potassium in soils

Potassium is an element that promotes plant development and growth (Wicklander, 1954). It is considered to be the most important element present in all living cells (Nijimbere et al., 2020). Potassium is required for several enzymatic functions and for the metabolism of proteins and carbohydrates. Its content depends on the physicochemical properties of the soil [USSL, 1954].

The results of the exchangeable potassium analyses of the soils studied show extreme values at most of the stations (Table 9, Fig. 9). Site SZ1, at a depth of 0–20 cm, has the highest level of exchangeable potassium (542.3 ppm), while site SZ7, at a depth of 20–40 cm, has the lowest level at 78.3 ppm. This increase may be due to the excessive use of potassium fertilisers. This is in agreement with results obtained on Zaër soils which show that the amount of potassium in the soil varies from 147 to 708 ppm [Benbrahim et al., 2017].

Exchangeable soil bases

The results of the exchangeable base analyses of the soils studied show that calcium is the most abundant cation, followed by magnesium, while sodium levels are very low. It is the most dominant element, accounting for 70% to 80% of exchangeable cations in all the soils [Touhtouh et al., 2014].

During the spring season, the levels of exchangeable Ca^{2+} recorded at the various sites varied considerably. In the surface horizons, they

Table 8. Assimilable phosphorus levels in the soils studied

Stations	Depth (cm)	P_2O_5 (ppm)	Interpretation
SZ_1	0–20	69.1	High
	20–40	49.1	
SZ_2	0–20	40.8	High
	20–40	30.2	
SZ_3	0–20	52.4	High
	20–40	28.9	Medium
SZ_4	0–20	173.6	High
	20–40	109.6	
SZ_5	0–20	189.8	High
	20–40	154.7	
SZ_6	0–20	210.1	High
	20–40	146.9	
SZ_7	0–20	158.2	High
	20–40	138.8	
SZ_8	0–20	121.2	High
	20–40	71.8	
SZ_9	0–20	82.4	High
	20–40	42.4	
SZ_{10}	0–20	51.8	High
	20–40	34.3	
SZ_{11}	0–20	48.1	High
	20–40	37.0	
SZ_{12}	0–20	52.7	High
	20–40	49.7	
SZ_{13}	0–20	52.1	High
	20–40	36.2	

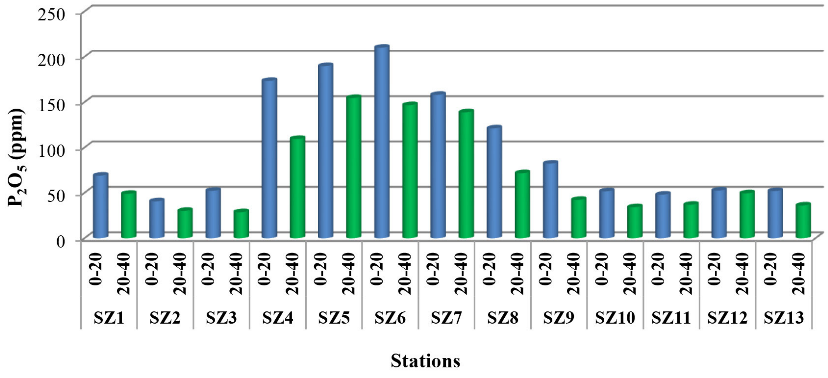

Figure 8. Assimilable phosphorus levels in the soils studied as a function of depth during the spring season

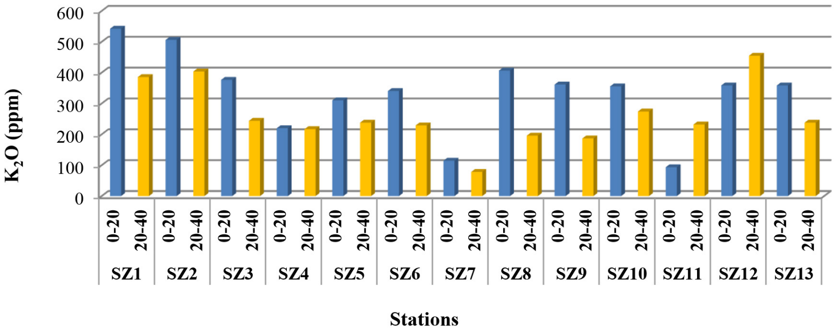

Figure 9. Exchangeable potassium levels during the spring season in soils studied under two horizons (0–20 cm) and (20–40 cm)

Table 9. Exchangeable potassium content of soils studied under two horizons (0–20 cm) and (20–40 cm)

Stations	Depth (cm)	K$_2$O (ppm)	Interpretation
SZ$_1$	0–20	542,3	High
	20–40	385,6	Medium
SZ$_2$	0–20	506,1	Very high
	20–40	403,7	Very high
SZ$_3$	0–20	376,6	Very high
	20–40	244	High
SZ$_4$	0–20	219,9	High
	20–40	216,9	High
SZ$_5$	0–20	310,3	Very high
	20–40	238	High
SZ$_6$	0–20	340,4	Very high
	20–40	229	High
SZ$_7$	0–20	114,5	Provided
	20–40	78,3	Low
SZ$_8$	0–20	406,7	Very high
	20–40	195,8	High
SZ$_9$	0–20	361,5	Very high
	20–40	186,8	High
SZ$_{10}$	0–20	355,5	Very high
	20–40	274,1	High
SZ$_{11}$	0–20	93,4	Low
	20–40	232	Provided
SZ$_{12}$	0–20	358,5	Very high
	20–40	454,9	Very high
SZ$_{13}$	0–20	358,5	Very high
	20–40	238	High

ranged from 7.5 meq/100g (SZ$_3$) to 74.5 meq/100g (SZ$_2$), while in the deeper horizons they fluctuated between 4 meq/100g (SZ$_7$) and 89 meq/100g (SZ$_{10}$) (Fig. 10).

Exchangeable magnesium levels vary widely from site to site. These levels fluctuate between 1.5 meq/100g (SZ$_2$) and 20.5 meq/100g (SZ$_7$) in the surface horizons, while they range between 1 meq/100g (SZ$_{10}$) and 28.5 meq/100g (SZ$_8$) in the deep horizons.

Sodium levels are very low at all sites, with a more or less even distribution. They ranged from 0.3 (SZ$_4$, SZ$_5$, SZ$_7$ and SZ$_{12}$) to 1.4 meq/100g (SZ$_1$) in the 0–20 cm horizons, while the deeper layers had values ranging from 0.3 meq/100g (SZ$_4$ and SZ$_7$) to 1.2 meq/100g (SZ$_6$). With the exception of site SZ$_1$, all of the soils analysed do not show great variability in sodium levels with depth.

Cation exchange capacity of soils

Cation exchange capacity is a measure of the size of the reservoir of nutrients able to pass easily into the soil solution. It generally varies from 8 (sandy soils, poor in M.O) to more than 20 meq/100g (clay soils, rich in M.O) and indicates how full this reservoir is [Védie, 2008].

The results of analyses of the cation exchange capacity of the soils studied are lower during the spring season, with a rate of 7.4 meq/100g at site SZ6 (0–20cm) and around 1.6 meq/100g at site SZ7 (20–40cm) (Fig. 11). Soils with low CEC are sandy or silty soils, while soils with high CEC are clay soils [Kombienou et al., 2015].

Theoretically, CEC is a parameter that depends on both the clay fraction and the organic matter [Benhassine, 2006]. The coefficients of determination obtained, show that the clay fraction explains 0.2% of the variation in CEC, whereas organic matter explains only 100% of the variation in CEC. The quantity of exchangeable bases in these soils is therefore determined mainly by the organic matter and the chemical and organic amendments, and is not linked to the mineral fraction (Fig. 12).

The saturation rate of the clay-humus complex is determined by the product of the S/T ratio: V = (S/T) x 100 where S is the sum of exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+, K^+) in meq/100g of soil. The CEC and saturation rate values are

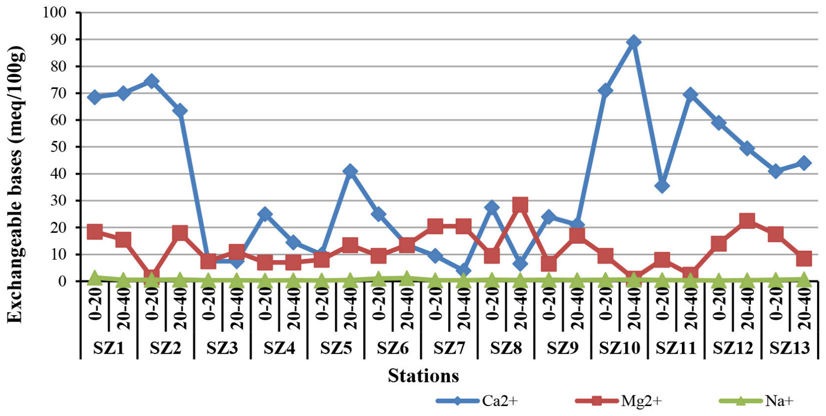

Figure 10. Variation in exchangeable base levels in the soils studied during the spring season

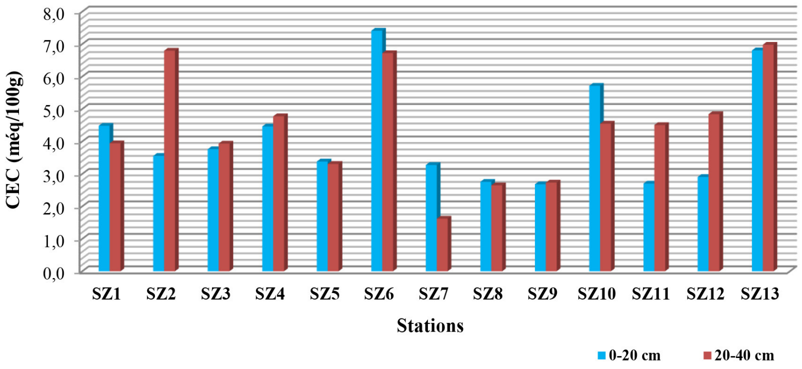

Figure 11. Cation exchange capacity of the soils studied

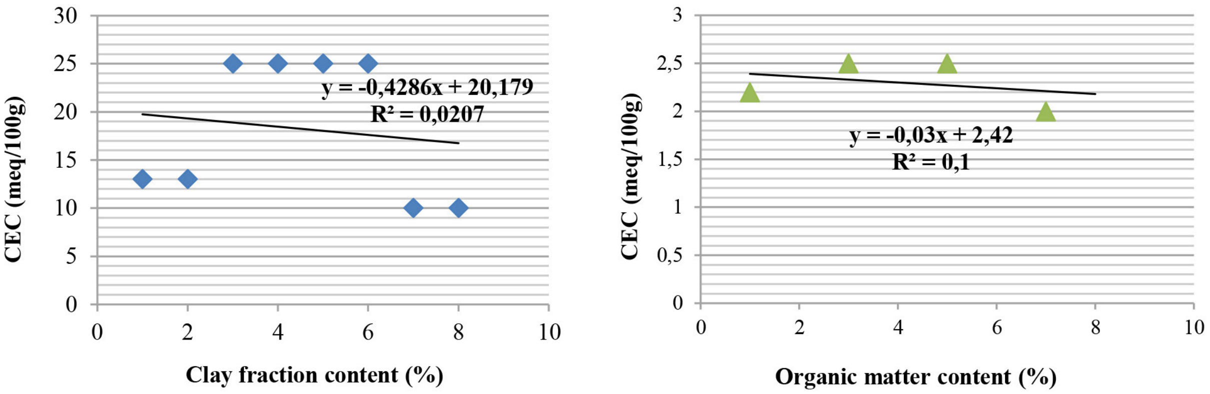

Figure 12. Relationship between CEC and clay fraction and organic matter content

presented in the CEC and saturation rate interpretation grid (Table 10, Fig. 13).

The results of the soil analyses studied show that the saturation rate of the clay-humus complex is very low. This is linked to the exchangeable bases and low cation exchange capacity of the soils studied. A saturation level of over 50 ensures good plant nutrition.

Statistical analysis

In order to better visualise the similarities observed previously and to better appreciate the behaviour of the physico-chemical parameters of the soils, 14 variables were used for the principal component analysis (PCA), namely clay, silt, sand, total limestone, equivalent humudity, water pH, electrical conductivity, organic matter, exchangeable potassium, assimilable phosphorus, exchangeable bases and the cation exchange capacity of two horizons (0–20 cm) and (20–40 cm).

The correlation test between the various physicochemical parameters studied enabled us to highlight (Table 11): positively significant correlations between pH water and silt; electrical conductivity and exchangeable sodium, as well as a moderate correlation between pH water and exchangeable potassium, pH water and organic matter, pH water and exchangeable calcium, exchangeable sodium and cation exchange capacity, calcium and exchangeable potassium, silt and exchangeable calcium and silt and exchangeable potassium. Highly significant negative correlations were recorded between silt and sand, organic matter and sand, water pH and assimilable phosphorus.

Correlation between physico-chemical parameters and soils in the surface horizon (0–20 cm)

The information provided by the factorial axes is presented in Table 12. These results vary from 5.01 to 2.95%, from 35.81 to 50.91%. The F1 axis alone represents almost all the information, i.e. 35.81% of the total inertia. The other axes (F2, F3 and F4) provide 21.10%, 13.90%, 13.90%, 10.708% and 6.01% respectively. The first four factorial axes explain approximately 81.52% of the total variability of the different active variables.

The first two axes (F1 and F2) define the main plane; they provide approximately 56.91% of the information. Observation of the correlation circle

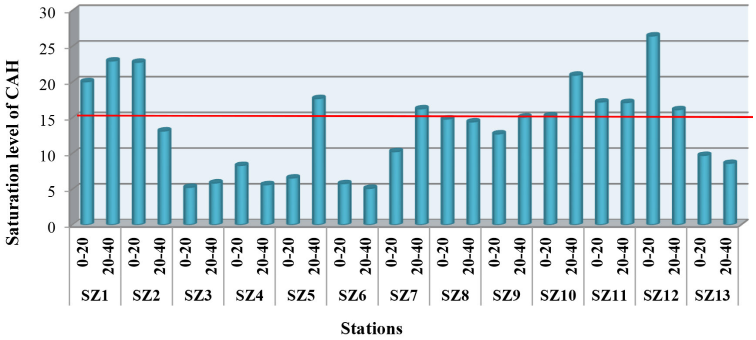

Figure 13. Saturation levels of the clay-humus complex in the soils studied

Table 10. Interpretation of CEC and saturation rate

CEC (Cation exchange capacity) (méq/100g soil)	< 5	5 – 10
	Very low	Low
S (Sum of exchangeable cations) (méq/100g soil)	< 2	2 – 5
	Very low	Low
%V = S/T·100 (Saturation level)	< 15	15 – 40
	Very low reserve	Low reserve

between the variables and the F1 and F2 factorial planes shows that silt, exchangeable calcium and water pH are well represented in the correlation circle and are close to axis 1, with a positive coordinate, and assimilable phosphorus, equivalent moisture and sand with a negative coordinate. Variables such as electrical conductivity, exchangeable sodium, organic matter and exchange capacity are close to axis 2. The higher soil's values in each of the above variables, the higher its coordinate on axis 1. Conversely, the lower the values, the more the soil will have a negative coordinate (Fig. 14).

Analysis of this graph of individuals revealed 3 discriminating groups (Fig. 15). Group G1 is represented by the variables % OM, % CEC, CE, NaO and P_2O_5, which are positively correlated with the F2 axis and represented by the only soil sample (SZ_6). Group G2 is represented by the variable % silt, CaO, K_2O, pHwater and limestone, which is positively correlated with the F1 axis and the soil samples SZ_1, SZ_2, SZ_{10}, SZ_{12} and SZ_{13}. In terms of granulometry, this reflects the predominance of the silty fraction and exchangeable calcium in these areas. Group G3 corresponds to factors negatively correlated with the F1 axis, i.e. % equivalent moisture, % sand, % clay and MgO, and to SZ_3, SZ_4, SZ_5, SZ_7, SZ_8, SZ_9 and SZ_{11} soils. This reflects the low concentration of group G3 factors in the stations sampled.

Correlation between parameters and soils in the deep horizon (20–40 cm)

The results of the principal component analysis of the 14 soil variables studied show that the first two axes present respectively 40.75% and

Table 11. Pearson correlation between the different parameters studied

Variables	Clay,%	Silt,%	Sand,%	Limestone,%	Humidity,%	pH water	CE	MO	P_2O_5	K_2O	NaO	CaO	MgO	CEC
Clay,%	1													
Sily,%	-0.19	1												
Sand,%	-0.36	-0.84	1											
Limestone,%	0.48	0.22	-0.48	1										
Humidity,%	-0.22	0.52	-0.37	-0.12	1									
pH water	0.09	0.78	-0.79	0.52	0.43	1								
CE	0.51	0.00	-0.28	0.07	-0.03	-0.19	1							
MO	0.49	0.64	-0.88	0.27	0.40	0.64	0.44	1						
P_2O_5	0.04	-0.40	0.36	-0.35	-0.24	-0.82	0.57	-0.22	1					
K_2O	-0.01	0.60	-0.56	0.56	0.15	0.67	0.02	0.38	-0.46	1				
NaO	0.23	0.38	-0.49	-0.16	0.00	0.12	0.70	0.57	0.18	0.10	1			
CaO	-0.02	0.63	-0.59	0.39	0.36	0.69	-0.09	0.54	-0.49	0.61	0.06	1		
MgO	-0.08	-0.14	0.18	0.03	0.07	-0.10	0.22	-0.23	0.18	0.08	-0.12	-0.47	1	
CEC	0.16	0.63	-0.69	0.23	-0.23	0.47	0.20	0.54	-0.23	0.49	0.67	0.35	-0.35	1

Table 12. PCA factorial axes for the soils studied

Specification	F1	F2	F3	F4
Own value	5,013	2,955	1,946	1,499
Variability (%)	35,811	21,104	13,902	10,708
Cumulative (%)	35,811	56,914	70,817	81,525

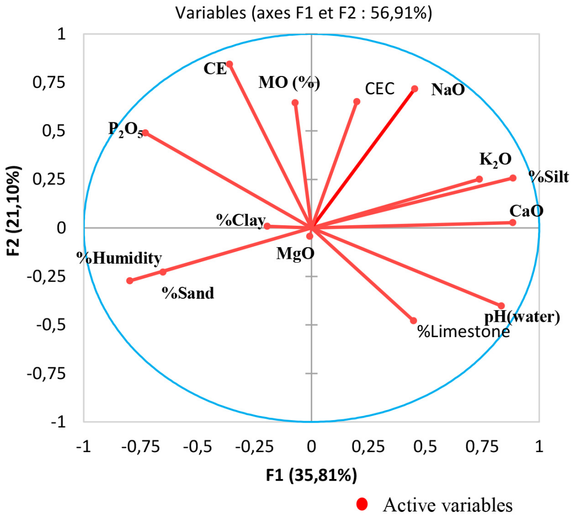

Figure 14. Projection of variables into the main F1 and F2 factorial planes

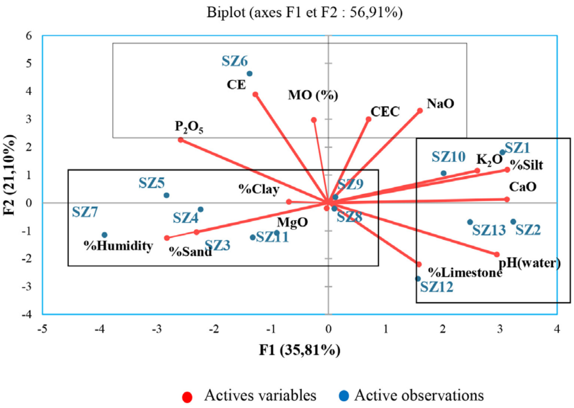

Figure 15. Projection of individuals into factorial planes F1F2

19.53% of the information, i.e. a total of 60.28% of the total variability. The correlation matrix of the variables analysed represents the correlation circle of the variables on the main plane (F1-F2). The first four factorial axes represent 82.16% of the total variability of the different active variables (Table 13). Observation of the correlations between the variables and the main axes shows that axis 1 is very well positively correlated with sand and negatively correlated with silt, CT, K_2O, CaO, water pH and equivalent moisture. Axis 2 shows a very good positive correlation with EC, NaO, P_2O_5, OM, CEC and clay.

Analysis of the first plane of the PCA indicates that most of the variables are all relatively well projected and negatively correlated with each other. The positive correlation is observed in relation to axis 1 for the variables MgO and sand (Fig. 16) and is opposed to the limestone content, % silt, CaO and K_2O, water pH and equivalent humidity, which are therefore negatively correlated with these variables in relation to the same axis. This correlation does not summarise enough of the variables used to construct soil quality indices.

Axis 2, on the other hand, is strongly influenced by CE, % clay, NaO, % OM, CEC and P_2O_5, which are located on the positive ordinates. This arrangement of variables makes it possible to identify an initial homogeneous group made up of coarse elements (sand), which move in the same direction, in opposition to the fine elements (silts) and total limestone in the soil. These are the areas subject to the effects of wind inputs, which promote soil degradation under wind action. These two processes therefore constitute the main mechanism for the evolution of these soils.

Projecting the individuals along the F1 axis revealed 2 main groups (Fig. 17). Group 1: individuals with high sand and MgO contents (SZ_3, SZ_4, SZ_5, SZ_7, SZ_8 and SZ_9); group 2 includes individuals with high levels of silt, limestone, K_2O, CaO, pH water and equivalent humidity (SZ_1, SZ_2, SZ_{10}, SZ_{11}, SZ_{12}, SZ_{13}); axis F2 includes group 3 with a single site (SZ_6) with high levels of EC, clay, NaO, MO, P_2O_5.

Table 13. Distribution of eigenvalues and variance along the various factorial axes

Specification	F1	F2	F3	F4
Own value	5,705	2,735	1,656	1,407
Variability (%)	40,753	19,535	11,826	10,050
Cumulative (%)	40,753	60,288	72,114	82,164

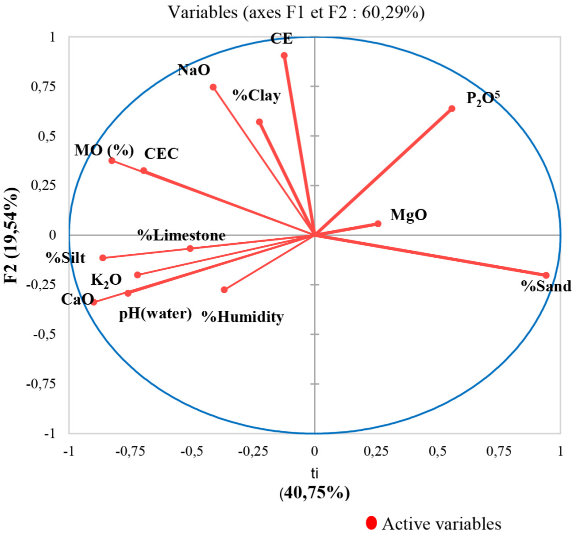

Figure 16. Correlation between variables and factorial planes F1 and F2

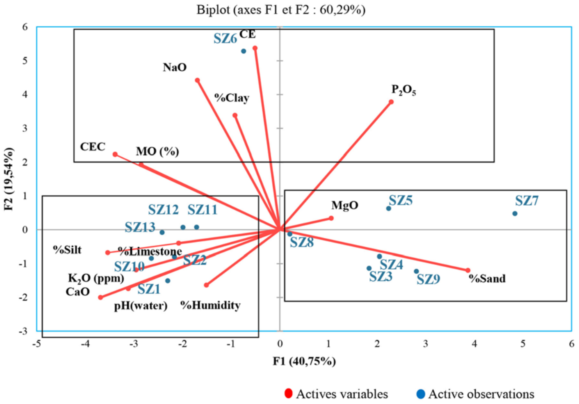

Figure 17. Projection of individuals into the F1 and F2 factorial planes

CONCLUSIONS

The Zaër region is one of the most important agricultural regions in central Morocco. This study contributes to the characterization and evaluation of the physico-chemical quality of the region's agricultural soils. Most of the region's soils have physical properties marked by a balanced silty-clay texture and a well-developed structure. Physico-chemically, the pH is moderately acidic to moderately alkaline. Organic matter levels are moderately poor to poor. These levels are explained by the low use of green manures (organic manure) and the intensification of cereal and legume crops. On the other hand, the soils are not affected by salinity problems, being rich in assimilable phosphorus and exchangeable potassium. The soils contain adequate levels of calcium and magnesium, with low levels of sodium during the prison season.

Regular monitoring and control of the soil is necessary for the sustainable use of this farmland. The CEC is relatively low, mainly due to the low levels of organic matter and clay fraction in the spring. In fact, it is essentially the mineral and organic fractions that are involved in cation exchange in the study area.

Intensive agricultural use in the Zaër region, the very low percentage of OM and the silty-sandy texture have a real impact on soil fertility. Hence the need to explore the potential for carbon storage in the soil in order to improve its quality and characteristics. The soil's organic matter and nitrogen content show the negative impact of intensive farming on soil quality in Zaër. Hence the need to resort to the use of organic soil improvers, which have a dual function of increasing soil fertility and agricultural yields.

To maintain the quality of the soil and its fertilisation in order to obtain good yields, it is necessary to regulate the quantity and nature of the clays and the quantity of organic matter present by encouraging optimisation with organic fertilisers.

REFERENCES

1. AFNOR. 2003. NFX31–107.
2. Baize D. 2000. Guide des analyses en pédologie: choix, expression, présentation, interprétation 2e éd, INRA-paris 255.
3. Benbrahim M., Ngo Thi., Morel Ch., Fioux Ph., Mustin C., Naisse Ch. 2017. Le BIOCHAR et la dynamique du phosphore des sols – Une synthèse des expérimentations françaises (novembre), Nantes, France.
4. Benhassine H. 2006. Nature minéralogique et role nutritionnel des argiles de sols céréaliers en région subhumide à semi-aride, Tunisie, C. R. Géosci. 338, 329–340.
5. Bower C.A., Reitemeier R.F., Fireman M. 1952. Exchangeable cation analysis of saline and alkali soils. Soil Sci, n° 73: pp. 251–261.
6. Combe M., Ferre M., et Thauvin J.P. 1975. Méséta centrale et Méséta côtière. Resssources en eau du Maroc, plaines et bassins du Maroc atlantique. Note et Mém. Serv. Géol. Maroc, Rabat, t. 11, n° 231, p 157- 171.
7. Commission de Pédologie et des Cartographie des Sols. 1967, p. 96.
8. DIAEA/DRHA/SEEN 2008. Direction de l'irrigation et de l'aménagement de l'espace Agricole, Service des Expérimentations, des Essais et de la Normalisation –Rabat.
9. El Hassani A. 1990. La bordure nord de la chaine hercynienne du Maroc, chaine "Caledonnienne"

des sehoul et plateforme nord-mésétienne. Thèse es-sciences, Strasbourg, 208.

10. El Khodrani N., Zouahri A., Douaik A., Omrania S., Iaaich H., Yahyaoui A., Fekhaoui M. 2017. Evaluation the Impact of Intensive Agriculture on Physic-Chemical Properties of Soil and Groundwater in the Rural Commune Sfafaa (Sidi Slimane, Gharb, Morocco); Journal of Materials and Environmental Sciences 8 (7); 2339–2346.
11. El oumlouki K., Moussadek R., Zouahri A., Dakak H., Chati M., El amrani M. 2014. Étude de la qualité physico-chimique des eaux et des sols de la région Souss Massa, (Cas de périmètre Issen), Maroc, 5 (S2) (2014) 2365–2374.
12. Félix-Faure B., Carrière M., Kalt S. 2013. Prendre en compte tous les indicateurs de l'acidité des sols pour l'interprétation et le conseil. 11èmes rencontres de la fertilisation raisonnée et de l'analyse COMIFER-GEMAS-Poitiers-Futuroscope 20 et 21 novembre.
13. Fotio D., Monkiedje A., Maniepi NJS., Nguefack J., Amvam ZPH.2004. Evaluation des résidus pesticide de leurs effets sur la qualité des récoltes du sol en zone périurbaine de Yaoundé a cultures maraicher resProceedings, Journée, Pole de Compétence en partenariat grand – Sud Cameroun (PCP). Résumés d'opérations de recherché participative menées en 2004, Yaounde, Cameroun.
14. Haritha M., SarveswaraRao M., Ajay kumar U., Punny k., Prof P.V.V. 2021. Prasada Rao. A case study on physico – chemical characteristics of agricultural soil around industrial area, Visakhapatnam, a. p, India. International Journal of Creative Research Thoughts. Volume 9, Issue 11.
15. Hartemink E.2010. Land use change in the tropics and its effect on soil fertility.19th World Congress of Soil Science, Soil Solutions for a Changing World. Brisbane, Australia,97, 63–76.
16. Holford, I.C.R. 1997. Soil Phosphorus: Its Measurement, and Its Uptake by Plants. Australian Journal of Soil Research, 35, 227–239. https://doi.org/10.1071/S96047.
17. Kekane SS., Chavan RP., Shinde DN., Patil CL., Saga SS. 2015. Physico-chemical properties of soil 3(4): 29–32.
18. Kombienou P.D., Arouna1 O., Azontondé A. H., Mensah G. A., Sinsin B. A. 2015. Caractérisation du niveau de fertilité des sols de la chaîne de l'Atakora au nord-ouest du Bénin, Journal of Animal &Plant Sciences, 2015. Vol.25, Issue 2: 3836–3856.
19. Labrecque L.I. and Milne G.R. 2011. Exciting Red and Competent Clue: The Importance of Color in Marketing. Journal of Academy of Marketing Science, 40, 711–727.
20. Laudicina V. A., Novara A., Barbera V., Egli M., and Badalucco L. 2015. Land Degradation and Development, 26(1), 45–53.
21. Mathieu C., Pieltain F. 2003. Analyse chimique des sols – Méthodes choisies, Éditions Tec&Doc, Lavoisier, 387 p.
22. Mekkaoui A.E., Moussadek R., Mrabet R., Chakiri S., Douaik A., Ghanimi A., Zouahri A. 2021. The conservation agriculture in Northwest of Morocco (Merchouch area): The impact of No-till systems on physical properties of soils in semi-arid climate. E3S Web Conf. 234, 00037, doi:10.1051/e3sconf/202123400037.
23. Nijimbere S., Kaboneka S., Ndihokubwayo S., Irakoze W., Ndikumana J. 2020., Caractérisation physico-chimique des sols d'une exploitation agricole du Mumirwa en commune Rumonge (Burundi).
24. Monographie. 2015. Ministère de l'agriculture, de la pêche maritime, du développement rural et des eaux et forêts : Région de Rabat-Salé-Zemmour-Zaër.
25. Mulaji C., Disa-Disa P., Kibal I., Culot M. 2016. Diagnostic de l'état agropédologique des sols acides de la province de Kinshasa en république démocratique du Congo (RDC), Comptes Rendus Chimie, 19, 820–826.
26. Olsen,S. R., Cole,C. V., Watanabe, F. S & Dean, L. A. 1954. Estimation of available phosphorus in soils by extraction with $NaHCO_3$, USDA Cir.939. U.S. Washington, p: 1–19.
27. Saber N., Mrabet R. 2002. Influence du travail du sol et des rotations de cultures sur la qualité d'un sol argileux gonflant en milieu semi-Aride Marocain. Etude et gestion des sols, 9, 43–53.
28. Schoonover J.E., Crim J.F. 2015. An introduction to soil concepts and the role of soils in watershed management. J. Contemp. Water Res. Educ, 154, 21–47.
29. Touhtouh D., Moujahid Y., El Faleh E.M., EL Halimi R. 2014. Physicochemical characterizations of three types of soils of Sais, Morocco. J. Mater. Environ. Sci. 5 (5) 1524–1534.
30. United State Salinity Laboratory Staff (USSL) 1954. US Department of Agriculture, Handbook n°60, U. S. Gov. Print.
31. Van Rast E., Verloo M., Demeyer A., Pauwels J.M. 1999. Manual for the soil chemistry and fertility laboratory-analytical methods for soils and plants, equipment, and management of consumables. NUGI 835, Ghent, Belgium, 1999, 243, Carquefou.
32. Védie H. 2008. La fertilité des sols : évaluation et amélioration. Rencontres Techniques Agriculture Biologique Légumes CTIFL ITAB, (28 janvier).
33. Walkley A., Black I.A. 1934. An examination of the degtjareff method for determining soil organic matter, and a 438 proposed modification of the chromic acid titration method. Soil science, 137, 29–38.
34. Wicklander L.1954. Forms of potassium in the soil. Potassiun symposim, Intern. Potash Inst., Bern, Switzerland, 109–121.