Evaluation Of Agricultural Soil Fertility And Quality In The Semi-Arid Region Of Zaër (Morocco)

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Abstract
The principal objective of this study is to assess the fertility levels of agricultural soils in the semi-arid region of Zaër. To this end, thirteen soil samples were taken during a sampling campaign carried out in autumn 2021 in the first superficial layers (0-20 cm) and at depth (20-40 cm). To determine the state of fertility, physico-chemical analyses were carried out for each site, namely particle size, total limestone, pH, organic matter, electrical conductivity, exchangeable potassium, assimilable phosphorus, cation exchange capacity and exchangeable bases.

The soil results indicate that the soils in the study area are moderately acidic to moderately basic, with a pH between 5.8 and 7.9. The electrical conductivity measured in the sampled soils indicates that the soils studied remain within the limits of non-saline soils (EC < 0.6 mS/cm). Total limestone levels are below 3%, indicating that the soils studied are poor in limestone. The soils studied are relatively poor in organic matter, preventing active microbial life. However, exchangeable calcium and magnesium concentrations were found to be low, as were sodium levels. Furthermore, cation exchange capacity is high in autumn, reflecting the soil's high and low nutrient retention capacity. The available phosphorus levels analyzed show that the soils studied are reduced and that the response of phosphorus fertilizer application in these soils is likely, as the phosphorus content determined is less than 40 ppm. Exchangeable potassium levels are low and insufficient, mainly due to the intensification of cultivation in these soils in the Zaër region and the lack of control over mineral fertilization. Our study shows that the soils studied have a silty-sandy-clay texture, are mostly low in limestone and poor to moderately poor in organic matter.

Key words: soil fertility, physico-chemical analysis, soil parameters, agricultural soil, semi-arid region, Morocco.

I. Introduction

Soil is a dynamic natural system containing minerals and organic components that create an environment conducive to plant growth [Velayutham and Bhattacharyya, 2000]. the physical, chemical and biological properties of soils enable them to supply quantities and quality of nutrients to achieve a balance conducive to plant growth. [Al-Zubaid, 2008; Parnes, 2013]. Fertile, productive soil proliferates life, while infertile, unproductive soil breeds hunger and famine.

Soil fertility is a function of numerous soil properties, many of which are interdependent. In most cases, the term "soil fertility" refers to a combination of current soil quality (mineral composition, soil texture) and achieved qualities such as soil structure, soil organic matter content and concentration of phosphorus.

One of the reasons for low productivity is nutrient extraction by continuous cultivation with low external nutrient input (more nutrients removed than added), nutrient extraction (high nutrient removal and no nutrient addition), acidification (lower pH), loss of organic matter and increase in toxic elements such as aluminium [Hartemink, 2003].

The Zaër region is considered as much as an agricultural zone known for cereal and leguminous, very important par excellence. However, population growth, the development of this agriculture, the reduction in fallow periods, the expansion of housing and the intensification of irrational soil use are leading to soil degradation, having detrimental consequences on crop output and soil quality. This deterioration in soil quality manifests itself in changes in soil properties, namely nutrient content (phosphorus, potassium, calcium, magnesium, sodium), pH, organic matter and cation exchange capacity. Declining soil fertility weakens soil structure [Adetunji et al., 2008], making it vulnerable to erosion. The decline in soil fertility in the region is induced by the increased removal of nutrients necessary for plant growth.

Based on the above, the present study aims to assess and monitor soil fertility in the Zaër region through a survey to be carried out in autumn 2021. The study involves characterizing physico-chemical parameters like the pH, organic matter, assimilable phosphorus, exchangeable potassium, exchangeable bases and cation exchange capacity).

II. Materials and methods

1. Study area

Our study location is in the province of Khémisset in northwest Morocco, 80 kilometers southeast of Rabat. With heights ranging from 200 to 500 meters, the study's coordinates are between latitude 33°30' and 33°45' North and longitude 6°24' and 6°45' West (Fig. 1). The primary geological formations in the area are Quaternary surface strata [El Omari et al., 2023] and Paleozoic schist bedrock [El Hassani, 1990]. They exhibit a wide variety of lithologies. The climate of the area is Mediterranean, with dry, scorching summers and cool, rainy winters

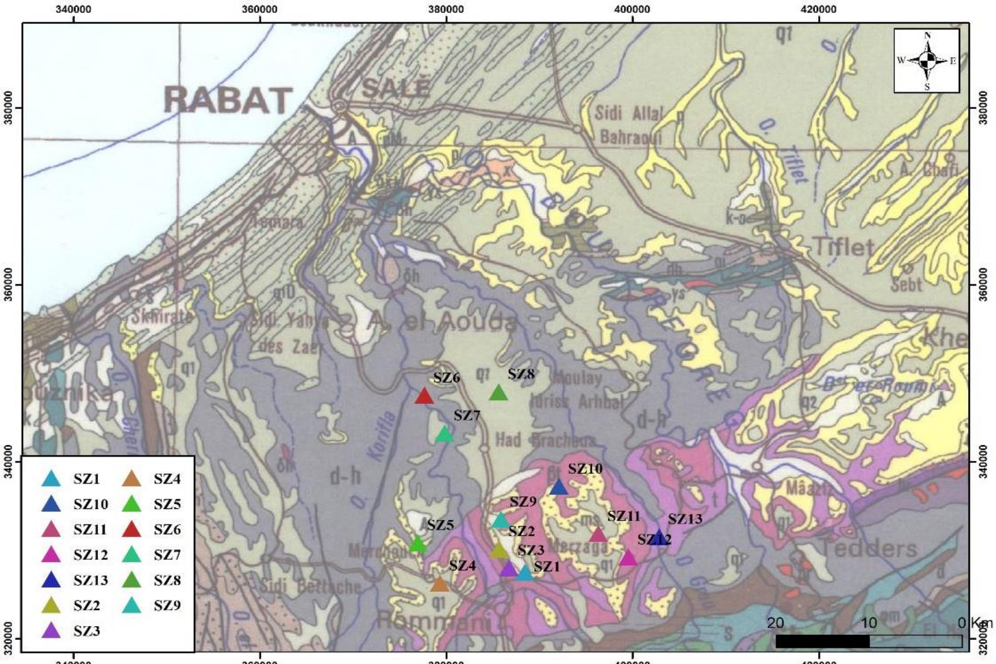

Figure 1. Map showing the study area's geology (El Omari et al., 2023)

The soil types found in the region are distributed as follows (Fig. 2):

- Vertisols: formed on Triassic red clay and basalt parent rocks located at the Rommani depression [El Omari et al., 2023];
- Vertisols: found throughout the Merchouch plateaux [Mekkaoui et al., 2021], produced on a parent rock of sandy marl and Miocene calcarenites (El Omari et al., 2023);

The isohumic soils found at Aïn Sbit have remnants of less evolved soils [Mekkaoui et al., 2021];

- Complex soils: corresponding to a mixture of burnished and crude mineral soils at Jamaa Moullablad [El Omari et al., 2023].

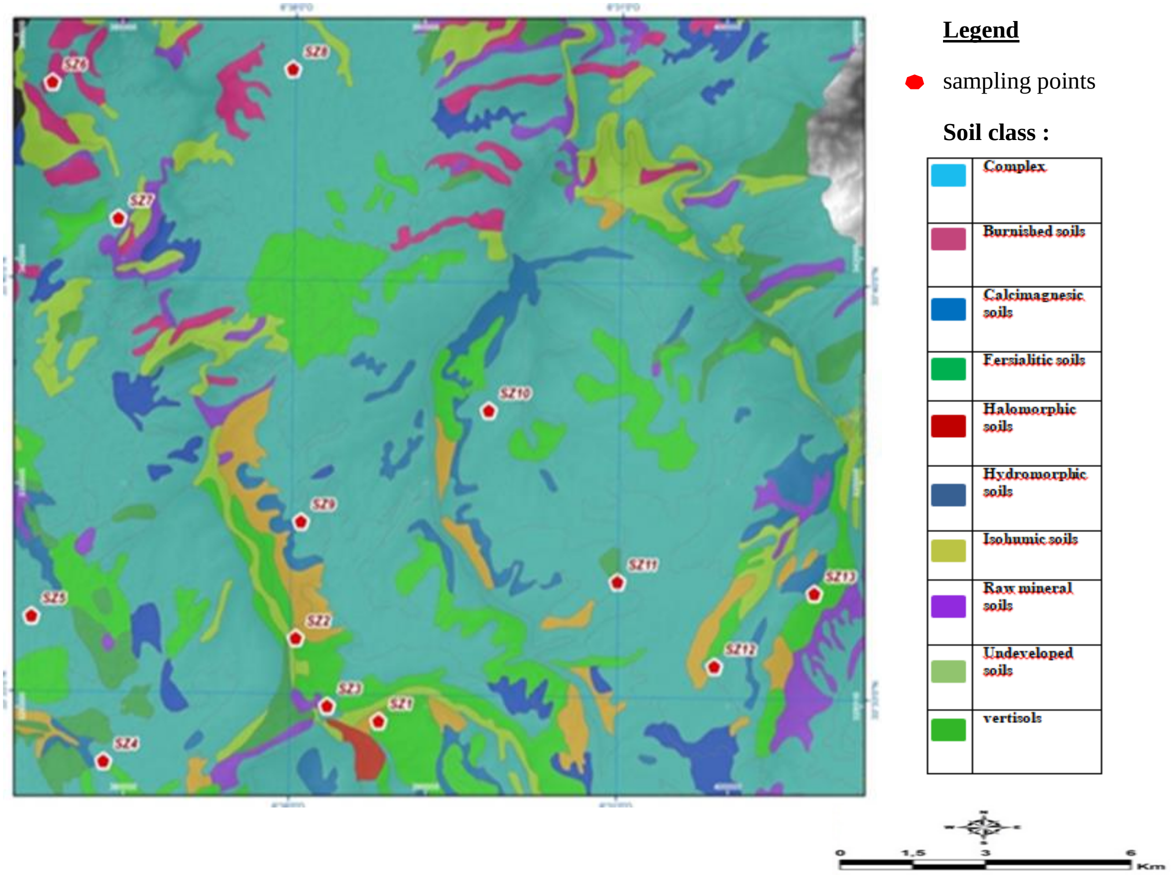

Figure 2. Different soil types distribution in the studied area [El Omari et al., 2023]

2. Sampling and analysis

In order to assess the physico-chemical characteristics of soil fertility in the Zaër area, 13 soils (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}) were sampled (Fig. 3) during the autumn season of 2021. Samples were taken at each site, one at a depth of 20 cm, the other at 40 cm. Sampling depended on several factors: soil homogeneity, geological and geomorphological contexts, pedological diversification such as the parent rock's characteristics, topography, exposure to slopes, types of soil, cropping history, yields, and methods.

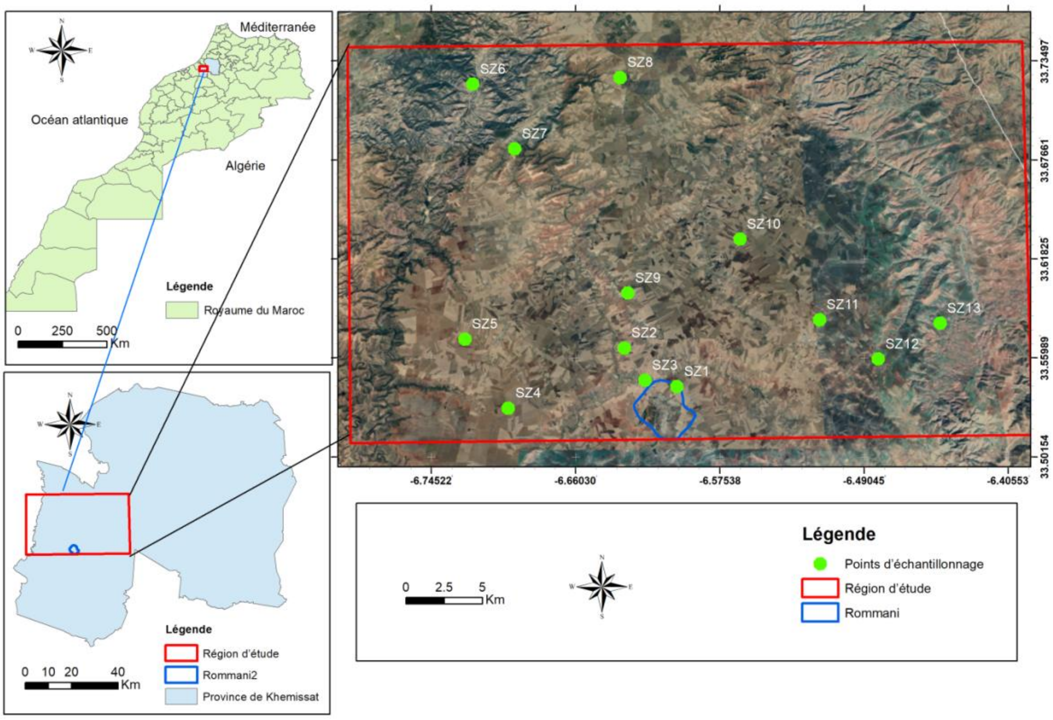

Figure 3. The thirteen study locations are located in semi-arid area of Zaër.

Soil samples were taken with an auger and blended to form a single composite sample. They were then air-dried, crushed and sieved to 2 mm. The methods used to the following physico-chemical characteristics of the soil samples were analyzed:

- **Granulometry:** Soil particles (clays, silts and sands) are separated using a Robinson pipette in accordance with AFNOR standard method NF X31-107 [Afnor, 2003];
-**The total limestone** was measured using the Bernard calcimeter method following an etching step with HCl 6N hydrochloric acid.
-**The pH water** was determined using an Orion conductivity meter, model 162, on a 1/2.5 soil/water solution (Mathieu and Pieltain, 2003).
- **Electrical conductivity (EC):** Expressed in mS/cm at 25°C, measurements were made on soil solutions containing a 1/5 saturated paste extract (U.S.S.L.S., 1954);
- **Organic matter (O.M.):** measured using the Walkley-Black method, which consists of titrating with Mohr's salt after potassium dichromate is used to cold oxidize the organic carbon component in an acidic medium. The following formula is used to determine the proportion of organic matter: According to Walkley and Black (1934), M.O. %= % C × 1.724;
- **Assimilable phosphorus (P_2O_5):** ascertained by the OLSEN technique, which involves extracting substances at a pH of 8.5 using sodium hydrogen carbonate [Olsen, 1954];
-**Exchangeable potassium (K_2O) and sodium (NaO)** are extracted at pH 7 using 1N CH3COONH4 ammonium acetate. The CL 378 flame photometer is used to measure the K2O and NaO levels. Percentages represent the results [Van Rast et al., 1999];Na+ is determined using 1N CH3COONH4 ammonium acetate at pH 7; exchangeable bases (CaO and MgO) are determined using 5N NaOH solution, 1/3 triethanolamine solution, and 5% KCN potassium cyanide solution [Bower et al., 1952];
- **The sodium** acetate method is used to assess the cation exchange capacity (CEC) [Bower et al., 1952].

Table 1 lists the guidelines for interpreting soil fertility that the Gharb Office of Agricultural Development uses. [DIAEA /DRHA /SEEN, 2008] (Table 1).

Table 1: Guidelines and interpretations for markers of soil fertility [DIAEA /DRHA /SEEN, 2008]

Parameters	Values	Interpretation
The pH water	< 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)	< 0,4	Non saline
	0,4 – 0,8	Not very saline
	0,8 – 1,6	Saline
	1,6 – 3,2	Highly saline
	> 3,2	Very strongly saline
OM (%)	< 0,7	Very poor
	0,7 – 1,5	Poor
	1,5 - 3	Moderately poor
	3 - 6	Rich
	> 6	Very rich
Assimilable 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
CEC (méq/100g soil)	< 5	5 à 10
	Very low	Low

Principal component analysis (PCA) is the multivariate approach utilized in statistical data processing, along with Pearson correlation and descriptive statistical analysis. Linear relationships between variables and persons are used in the factorial technique. It makes possible an effective graphical depiction that aids in the understanding of the connections between the variables and the observations. Excel Stat software was used to perform these statistical analysis of the data [El Omari., 2023].

III. Results and discussion

1. Characterization and spatial variation of physico-chemical parameters in the 0-20 cm depth range

1.1 Granulometry

The majority of the agricultural soils examined were found to have a predominance of the silty fraction, which was followed by the sandy fraction and the clay fraction, according to a textural study of the soils (Fig. 4).

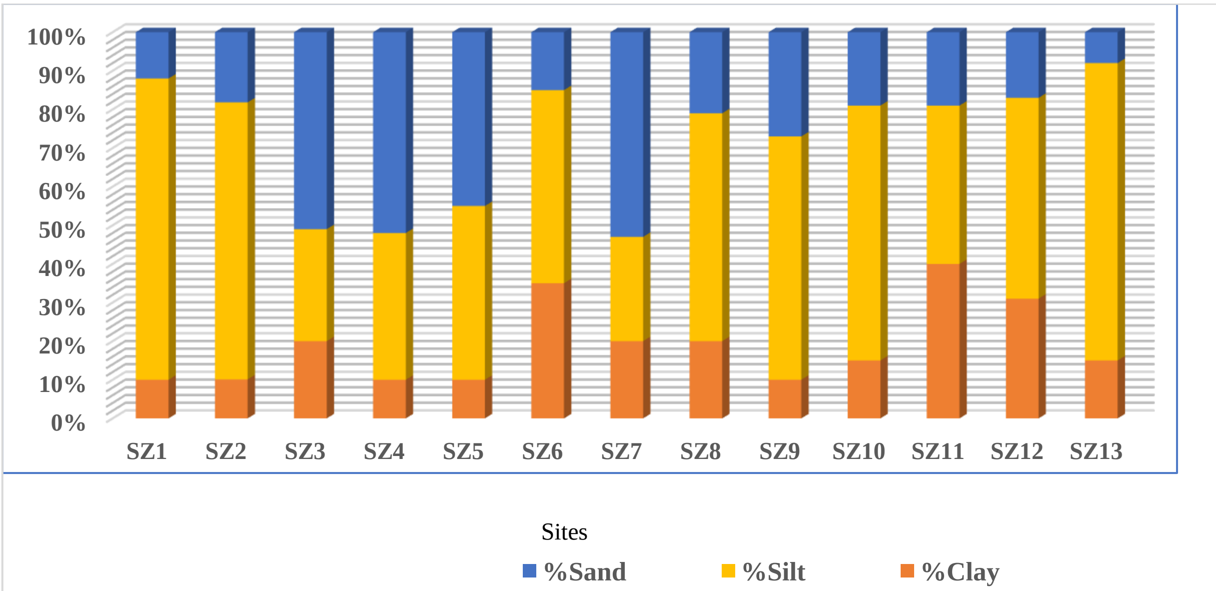

Figure 4. Physical constituents of the soils studied

The soils studied are made up of silt and sand in high proportion to clay. This mixture of fine particles (silt and clay) and coarse particles (sand) contributes to soil permeability and porosity, while ensuring the availability of water and nutrients needed by plants [Enyegue, 2012]. According to a study done in the spring of 2023 on the same soils in the Zaër region (El Omari et al., 2023), the silty fraction is more abundant than other soil constituents, containing, on average, 18% clay, 51% silt, and 30% sand.

1.2 Total limestone

The results for soils measured in the study area show that the majority of soils studied belong to the non-calcareous to slightly calcareous category (Fig.5). A certain increase may be due to the nature of the parent rock widespread in the study area, the agricultural nature and the use of fertilizers and soil improvers for crops. Monitoring of limestone content during the spring season shows that these soils also retain their non-calcareous character in spring and autumn of the same year [El Omari et al., 2023]. This balance in total limestone enables the creation of clay-humus complexes that have the ability to hold onto cations that are essential to plant nutrition [Baize, 2000].

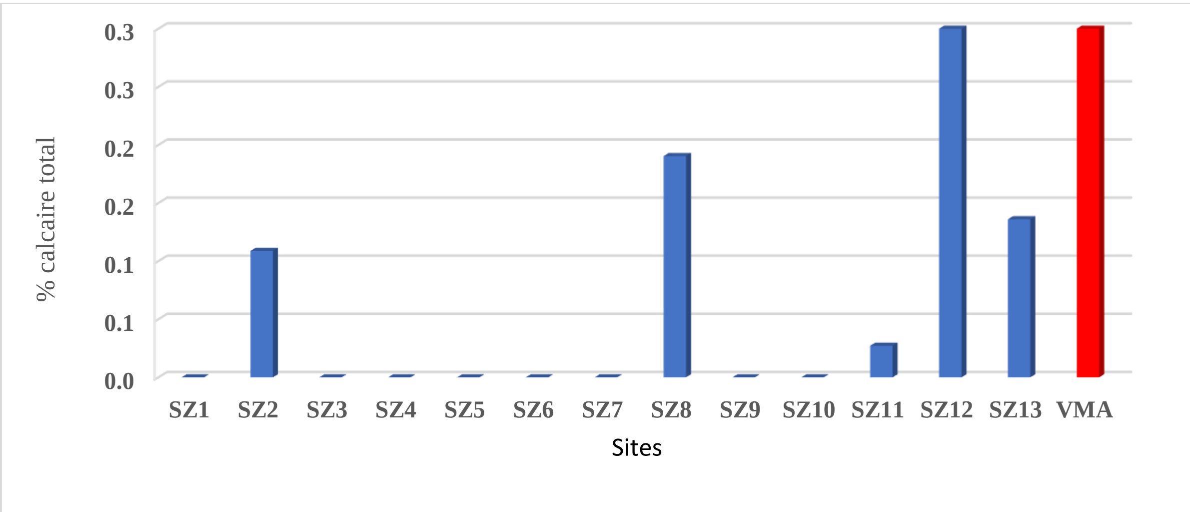

Figure 5. Percentages of total calcareous in soils of the study area

1.3 Soil pH

The results of soil pH analysis in the study area show that the majority of the soils studied have a moderately alkaline to weakly acidic pH (Fig. 6). Stations with a weakly basic pH (7.3 - 7.8) occupy 62% of all soils in the region and are spread over several areas of the region, while stations with a neutral pH (7.1 - 7.3) occupy a very small area (8%) and stations with a weakly acidic pH (6 - 6.5) and acidic pH (<6) occupy 15% of all soils in the study area.

The ΔpH values (pHKCl - pHwater) have a ΔpH close to zero, indicating a low content of exchangeable Al^{3+} contained in these soils. However, the rest of the soils have a largely negative ΔpH ranging from -0.8 to -1.2. These results show that the alkalinity of the soils studied can be linked either to the nature of the parent rock or to the enrichment of the soils in these regions in Ca^{2+} and Mg^{2+} cations; in this case, the phenomenon would be one of alkalinization with a generally low level of alkalinity.

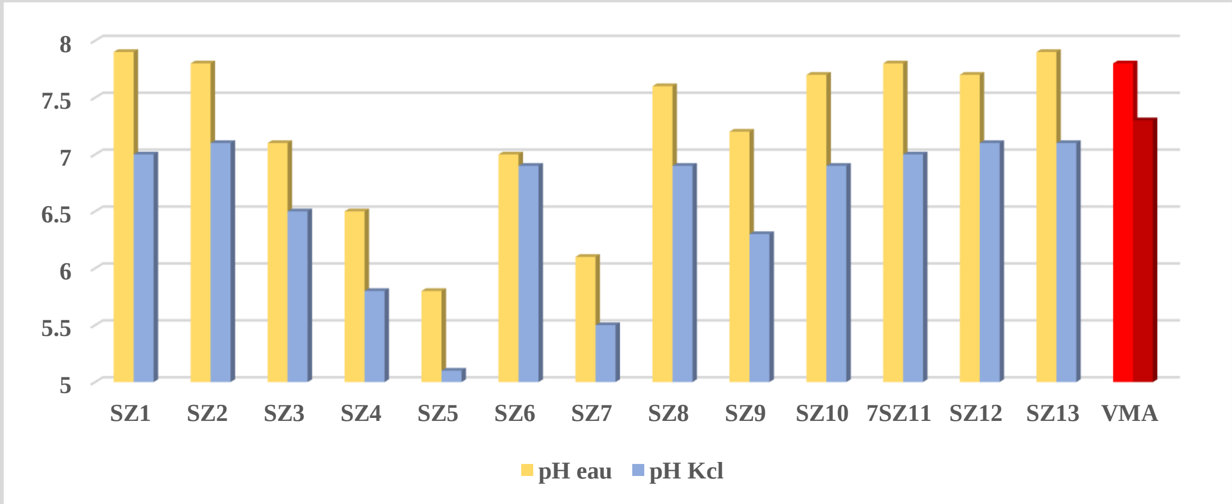

Figure 6. pH distribution of studied soils

1.4 Soil electrical conductivity

The results of the soil electrical conductivity analyses reveal that 98% of the soil samples tested were non-saline, while 2% of the sites studied were saline (Fig. 7). This high salinity is particularly noticeable at site SZ_6. This may be due, on the one hand, to an influx of salty water and high evaporation rates, which lead to the concentration of salts in the soil through insufficient leaching and, on the other hand, to the proximity of the water table [Marlet and Job, 2006; Olivier, 2014]. This salinity can lead to a drop in fertility, favoring toxicity phenomena for plants [Daoud et al., 1994]. With the exception of this site (SZ_6), the soils in our region show no negative effects on normal crop development and soil fertility.

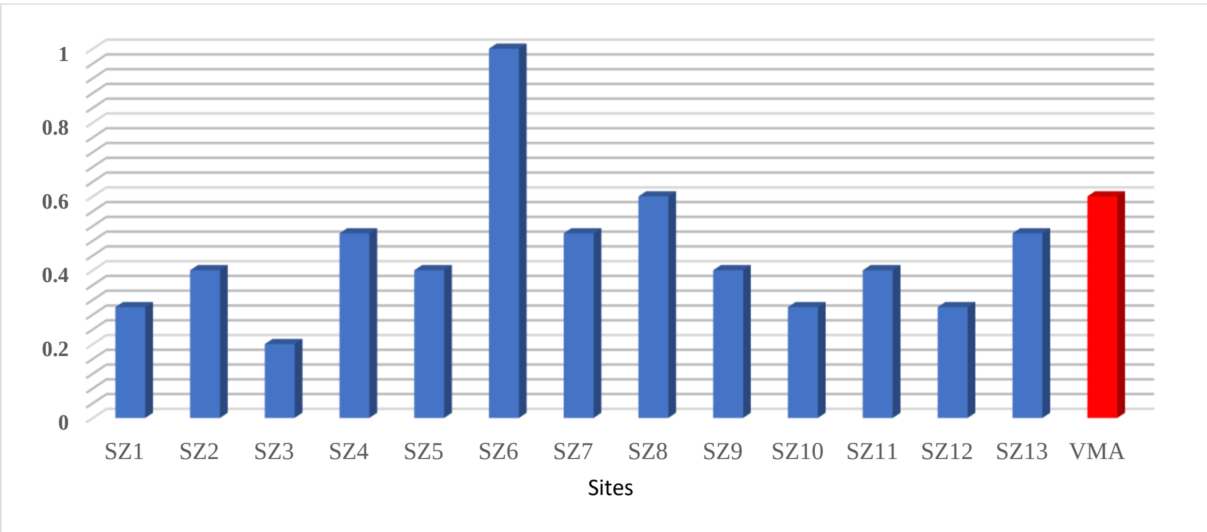

Figure 7. Electrical conductivity distribution of the soils studied

1.5 Soil organic matter

The organic matter content of the surface horizons (0-20 cm) of the profiles studied varies between 1.3% and 3.9% (Fig. 8). These low organic matter contents may be the result of several factors such as soil texture, farming practices, chemical fertilizers, the agricultural intensification widespread in the study area and the influence of the semi-arid climate; such factors induce a reduction in agricultural yields [Pieri, 1989].

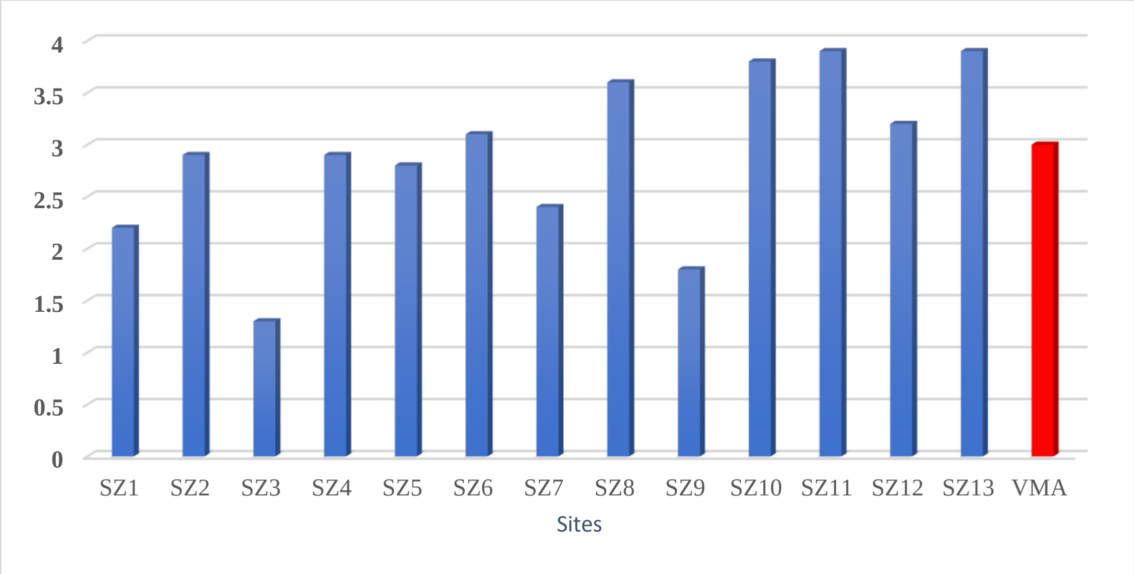

Figure 8. Distribution of Zaër soils according to organic matter content

1.6 Available soil phosphorus

Available phosphorus values in the study area vary from 1.6 ppm to 40.2 ppm, with an average value of 14.3 ppm. As a result of the plants using up all of the phosphorus so they can produce a strong crop, phosphorus levels are very low in the fall (Fig. 9). Low amounts of phosphorus in the soil have an adverse effect on photosynthesis, root development, and hence crop output capacity [Benbrahim et al., 2017].

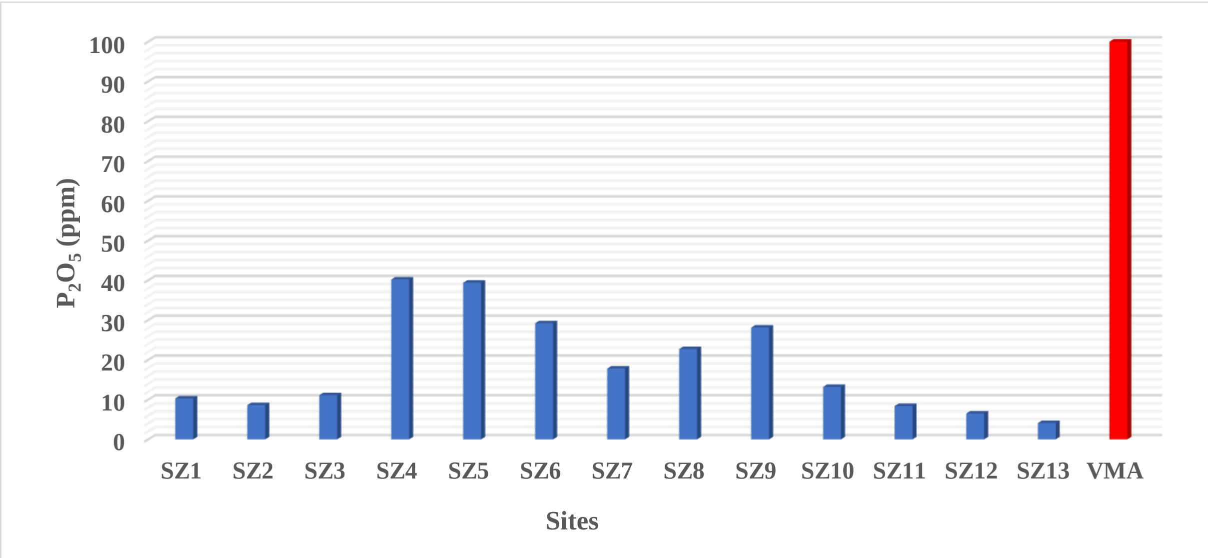

Figure 9. Assimilable phosphorus levels in soils studied during the autumn season

1.7 Exchangeable potassium in soils

The results of exchangeable potassium analysis of soils in the study area show moderate to high levels during the autumn season at the sites studied (Fig. 10). Soil rest or overuse of potassium fertilizers are considered to be the causes of the rise in exchangeable potassium. The cereal and legume crops studied could help these soils to re-establish a normal potassium supply to their crops, and make the most of high-yielding varieties.

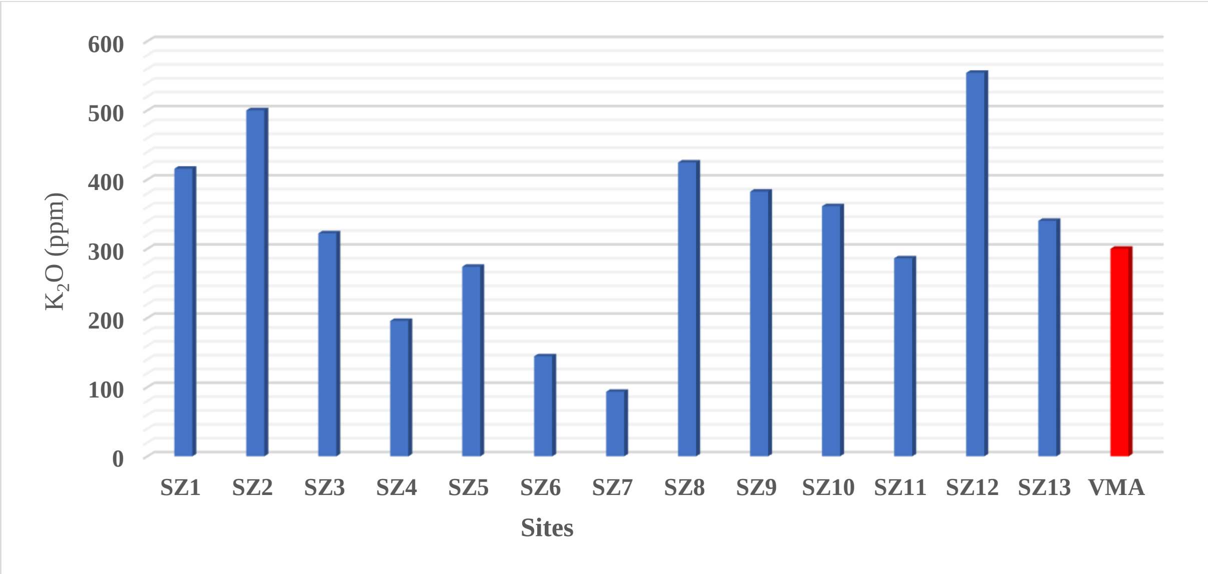

Figure 10. Exchangeable potassium concentrations in the investigated soils throughout the fall season

1.8 Exchangeable soil bases

During the autumn season, calcium concentrations decrease significantly in all soils in the region. These range from 3 (SZ_5) to 35.5 meq/100g (SZ_{13}) (Fig. 11). A drop in magnesium concentrations is revealed during this season. Concentrations range from 1 (SZ_{12}) to 11.5 meq/100g (SZ_5) and from 0 (SZ_{11}) to 10 (SZ_{13}). As for sodium, levels obtained during this season were very low and broadly similar to those recorded during the spring season of the same year [El Omari et al., 2023]. However, a high level was recorded at site SZ_6 (3.5 meq/100g).

The spatial evolution of sodium shows a similarity to that of electrical conductivity, proving that this chemical element is the main culprit in soil salinity. Sodium is not a nutrient for plants; in excess, it is detrimental to plant growth. Increased sodium levels are also responsible for degrading soil structure and reducing permeability. In this case, gypsum must be added to replace the exchangeable sodium in the absorbent complex with calcium.

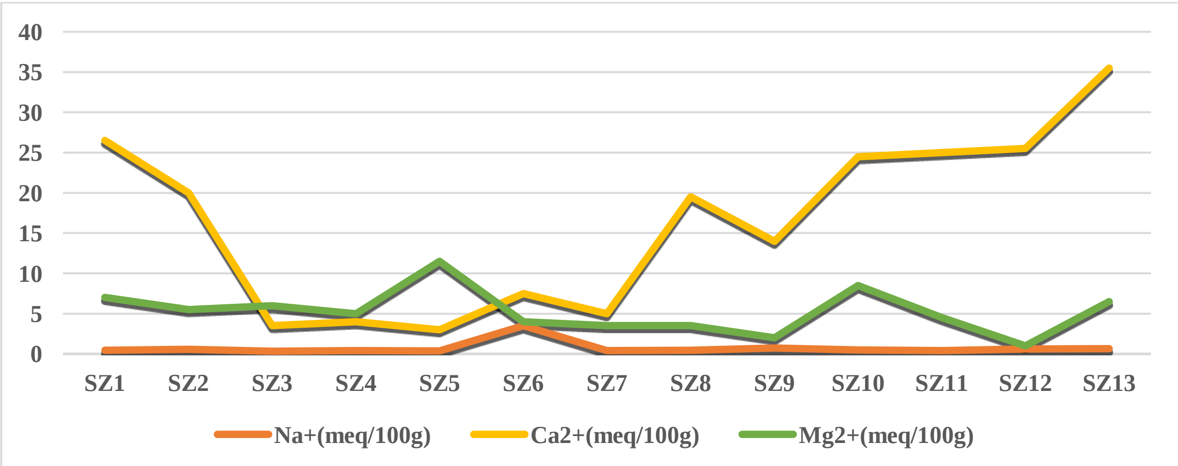

Figure 11. Variations in exchangeable base levels in the soils under study in the fall seaon

1.9 Soil cation exchange capacity

The Zaër region's soils' ability to exchange cations is relatively high during the autumn (Fig. 12). It is around 73.4meq/100g at site SZ_{13}. Furthermore, CEC is higher at depth than at the surface. The CEC of the same soils remains low during the spring season [El Omari et al., 2023]. This means that CEC is influenced by seasonal changes. It should be noted that during the spring season all soils have low reservoirs, whereas during the autumn season, soils represent reservoir varieties.

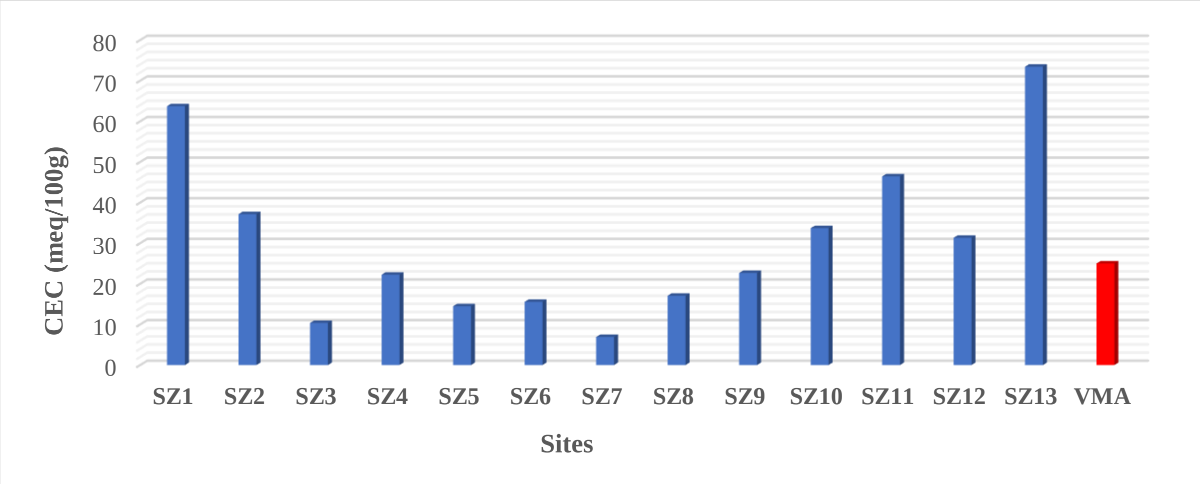

Figure 12. Cation exchange capacity of the soils studied

1.10 Statistical analysis

Principal component analysis of physico-chemical soil parameters in the Zaër region shows that the information provided by the factorial axes varies from 5.67 to 2.76%. Nearly all of the information, or 43.64% of the total inertia, is explained by the F1 axis alone. The remaining axes (F2, F3, and F4) yield 21.24%, 14.41%, and 7.64%, in that order. Roughly 86.95% of the overall variability of the several active variables may be explained by the first four factorial axes (Table 2).

Table 2. principal PCA factorial axes for the examined soils

Factor axes	**F1**	**F2**	F3	F4
Tidy value	5,674	2,762	1,874	0,994
Variability (%)	43,643	21,244	14,415	7,649
% cumulative	43,643	64,886	79,301	86,950

The correlation circle between the variables and the F1 and F2 factorial planes may be observed, and it can be seen that assimilable phosphorus and sand have a negative coordinate, while exchangeable calcium and water pH are well represented in the correlation circle and near axis 1. Axis 2 is in close proximity to variables like exchangeable sodium, electrical conductivity, and clay. On axis 1, a soil's coordinate rises with increasing values in each of the aforementioned factors. Vice versa, the soil will have a negative coordinate when the values are low (Fig. 13). These values are partially identical and compatible with data found in spring of the same year and on the same soils in the study region.

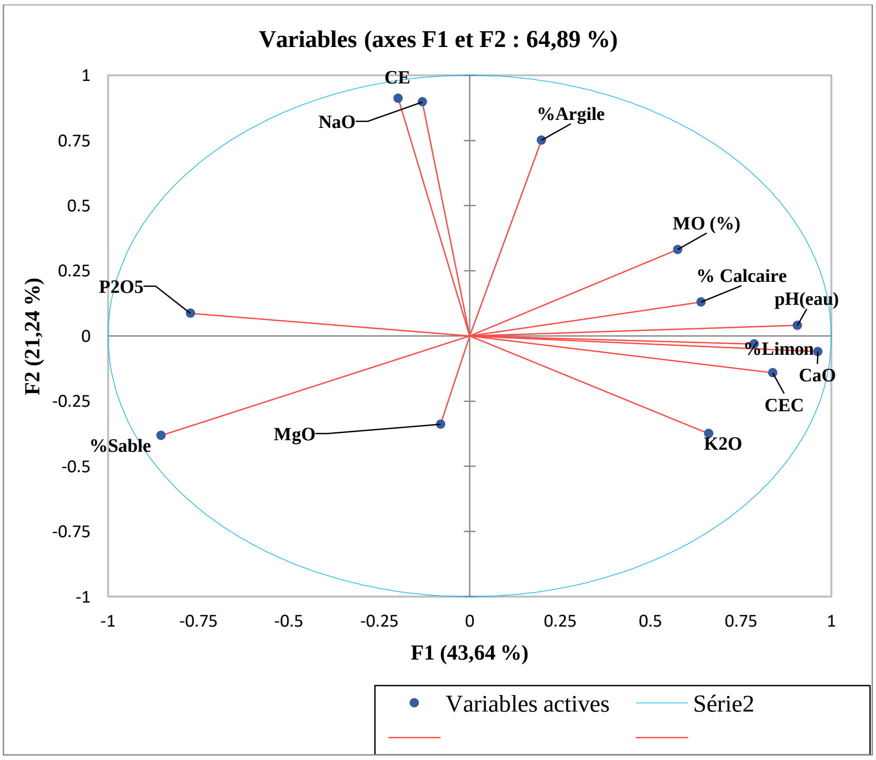

Figure 13. Variables projected into the primary F1 and F2 factorial planes

Three distinct groups were identified by individual graph analysis (Fig. 14):

-Group G1 is represented by the variables CE, NaO, and clay, which are positively correlated with the F2 axis and represented by a single soil sample (SZ_6). This suggests that in these soils, exchangeable calcium and the silt fraction predominate (El Omari et al., 2023);

-Group G2 is represented by the variables % silt, CaO, K2O, pH water, % OM, CEC, % silt, and limestone, which are positively correlated with the F1 axis and soil sites SZ_1, SZ_2, SZ_{10}, SZ_{11}, SZ_{12} and SZ_{13};

- The components in group G3, which include percentages of sand, P2O5, % sand, and MgO, as well as site-specific factors like SZ_3, SZ_4, SZ_5, SZ_7, SZ_8 and SZ_9, are inversely linked with the F1 axis.

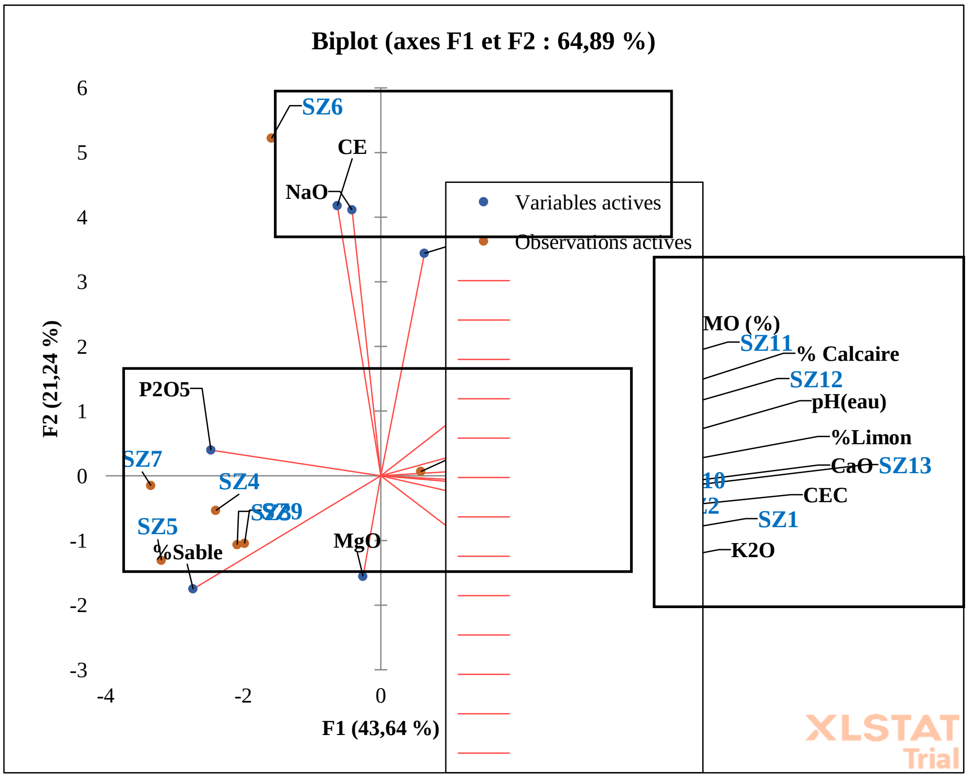

Figure 14. Projection of individuals in factorial planes F1F2

2. Characterization and spatial variation of physico-chemical parameters at depths of 20-40 cm

2.1 Granulometry

The results of the particle size analyses presented in figure 15 show the dominance of the silty fraction in the majority of the stations studied, with an average value of 51%. The average sandy fraction is around 30%, while the clay fraction is present with low values, averaging 18%).

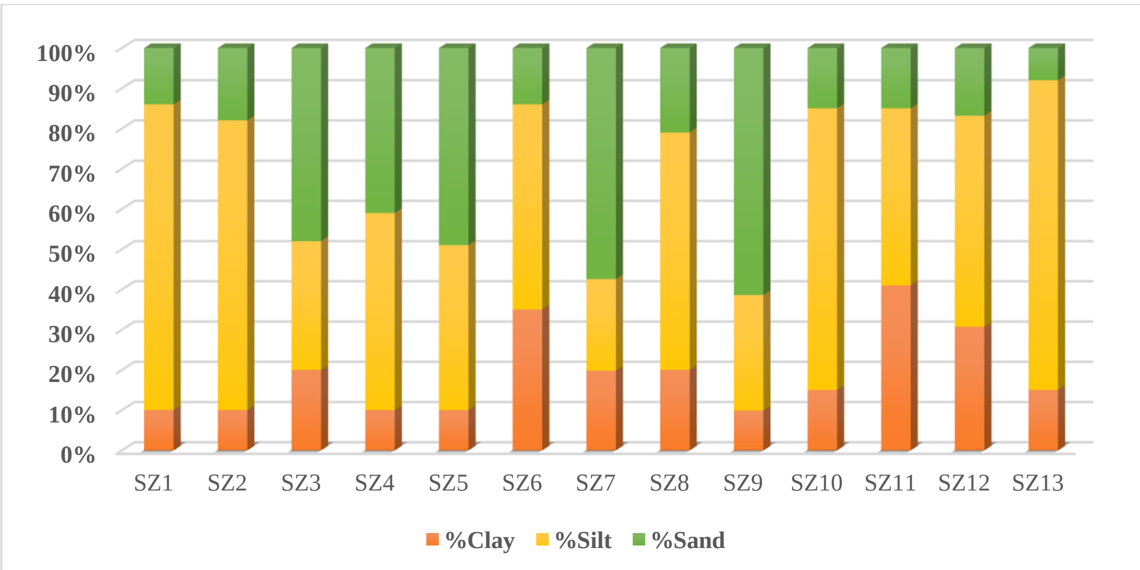

Figure 15. Percentage of clays, silts and sands in study area soils

2.2 Total limestone of soils

Measured soil results for the study area show that 77% of soils belong to the non-calcareous to slightly calcareous class, and 23% belong to the moderately calcareous class (Fig. 16). This would appear to be due to the type of parent rock widespread in the study region, as well as to the agricultural nature of the area and the extensive use of fertilizers and soil improvers for cultivation.

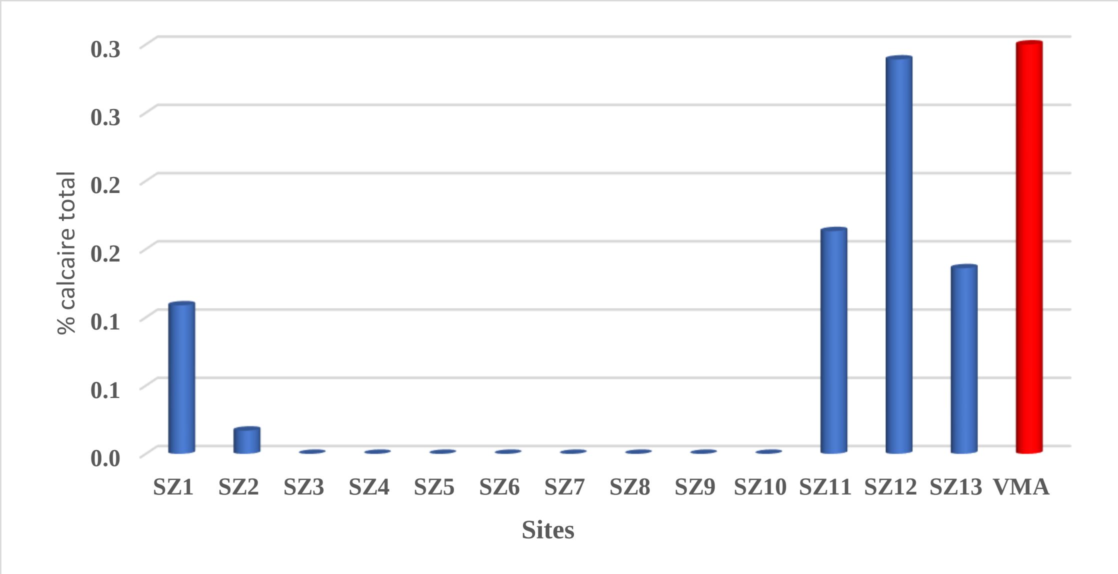

Figure 16. Percentages of total limestone in soils in the study area

2.3 Soil pH

The results of the soil pH analysis show that most of the soils studied have average alkaline to weakly acidic pH values (Fig.17). This alkalinity of the soils studied can be related either to the nature of the parent rock or to an enrichment of the soils in these regions in cations (Ca^{2+} and Mg^{2+}). This is a phenomenon of alkalinization, with a generally low level of alkalinity.

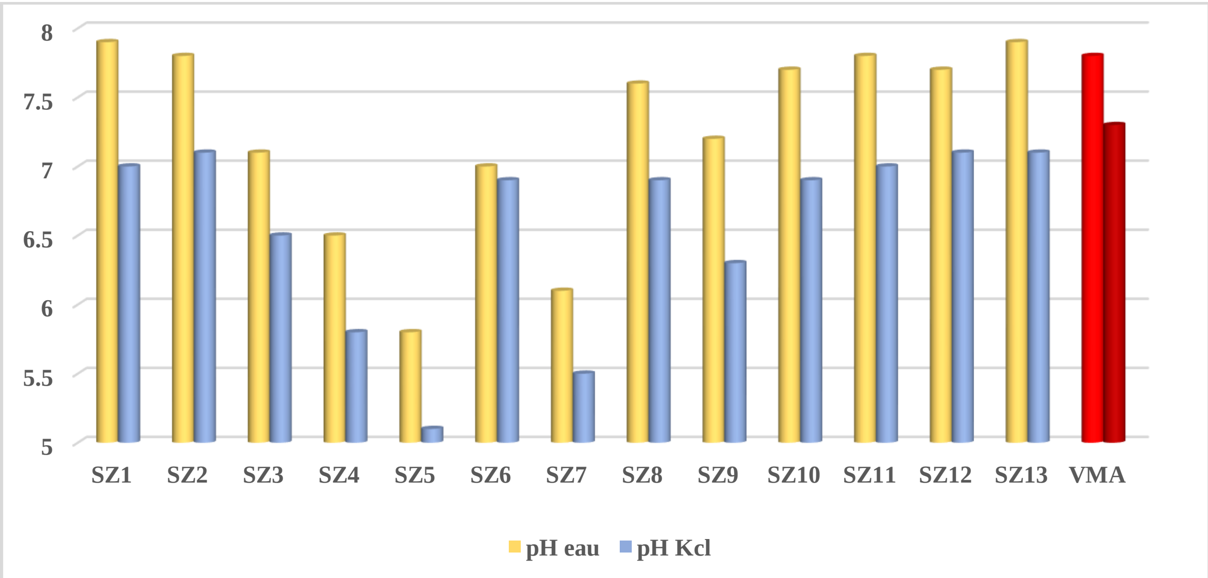

Figure 17. Soil pH distribution in the study area

2.4 Electrical conductivity of soils

Electrical conductivity results for soils in the study area are slightly low (< 0.4 mS/m) for 92% of all soil samples, with saline soils accounting for 8%. Site SZ_6 shows the highest electrical conductivity values (4.9 ms/cm), Conversely, siteSZ_7 (Fig. 18) represents the value of 0 ms/cm.

Figure 18. Soil electrical conductivity in the autumn as a function of depth

2.5 Soil organic matter

The results of the soils studied show that 53% of the soils have an average level of organic matter; 42% of the soils studied have a high level of organic matter, while 5% have a low level of organic matter (Fig. 19).

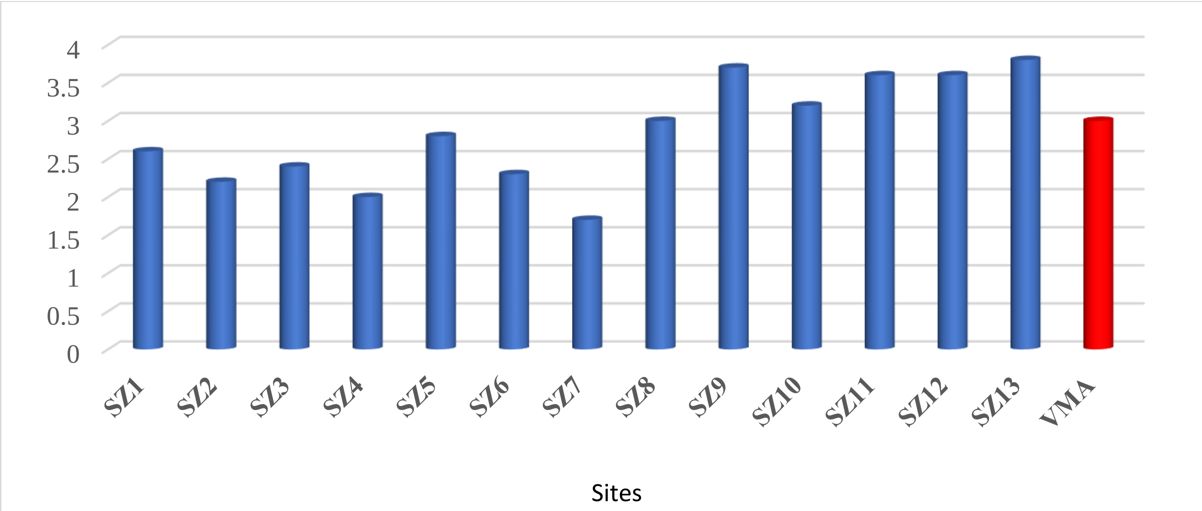

Figure 19. Distribution of soils in the Zaër region according to their organic matter content

2.6 Assimilable soil phosphorus

Assimilable phosphorus values in the study area range from 1.6 ppm (site SZ_8) to 32.7 ppm (site SZ_5), with an average of 10.16 ppm (Fig. 20). Phosphorus levels are very low during the autumn season; this would be due to the depletion of this element by plants during the autumn season when harvesting was carried out, and the soils are dry and very compact.

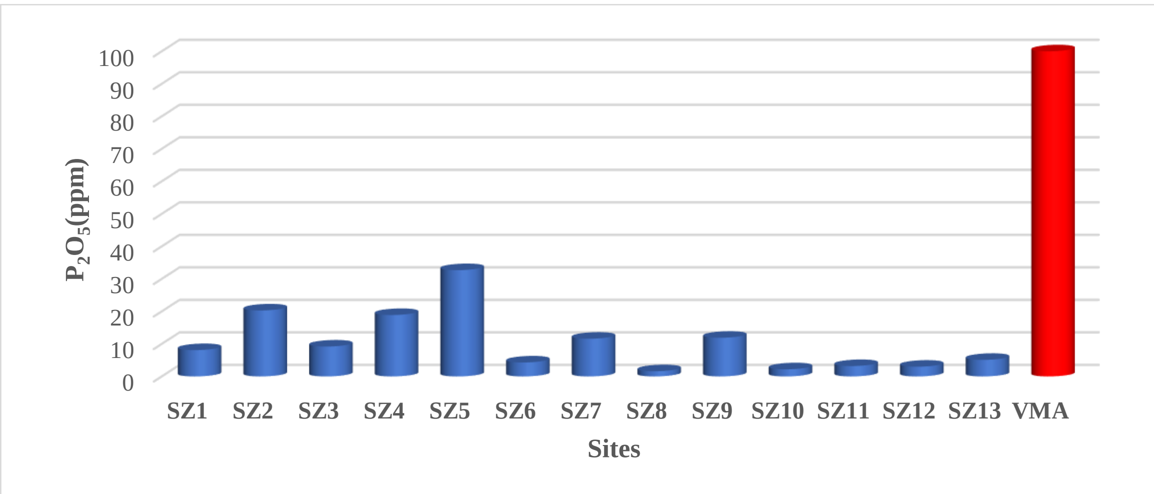

Figure 20. Assimilable phosphorus concentration of soils investigated in the fall as a function of depth

2.7 Exchangeable potassium in soils

The findings of the soils' exchangeable potassium analysis in the study area are presented in figure 92, which shows that the values vary in distribution between 60.3% (site SZ_7) and 575.4% (site SZ_3), with an average of 255.60%. The increase in exchangeable potassium (Fig. 21) possibly as a result of the excessive use of potassium fertilizers or to soil rest under cereal and leguminous vegetation, which could help restore normal potassium supply to the crops and make the most of high-yielding varieties.

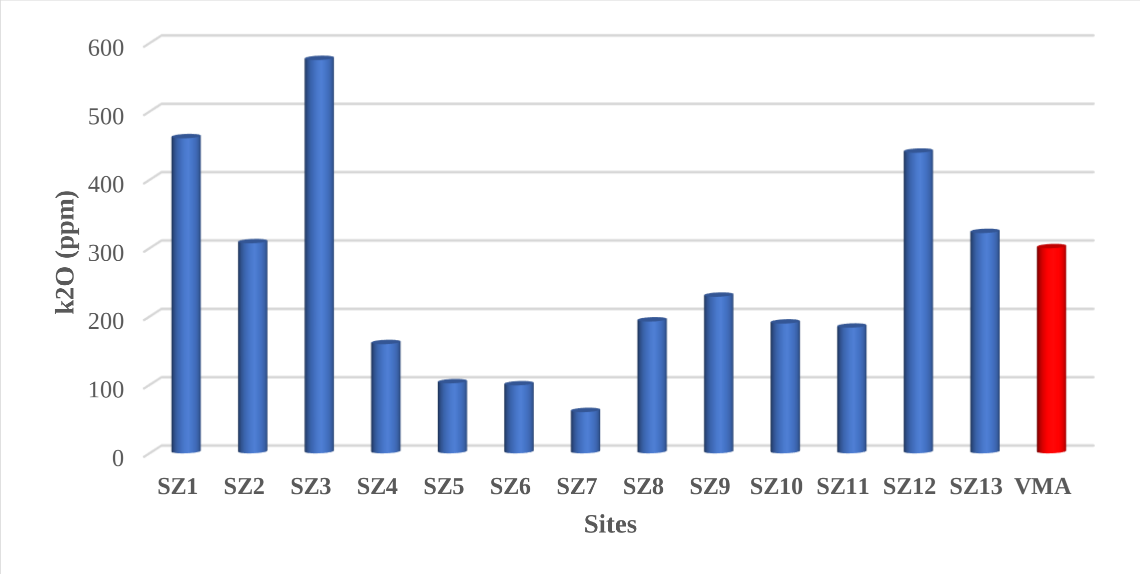

Figure 21. Exchangeable potassium concentrations in the investigated soils throughout the fall

2.8 Exchangeable soil bases

The calcium contents in the soils under investigation range from 1.5 (SZ_5) to 29 meq/100g (SZ_{11}), according to the results in the deep horizon (Fig. 22). A drop in magnesium concentrations is revealed during this season, ranging from 0 meq/100g (SZ_{11}) to 10 meq/100g (SZ_{13}). These levels are considered intermediate to high. High sodium levels were recorded at site SZ_6 with 4.4 meq/100g and 0.3 meq/100g at site SZ_7.

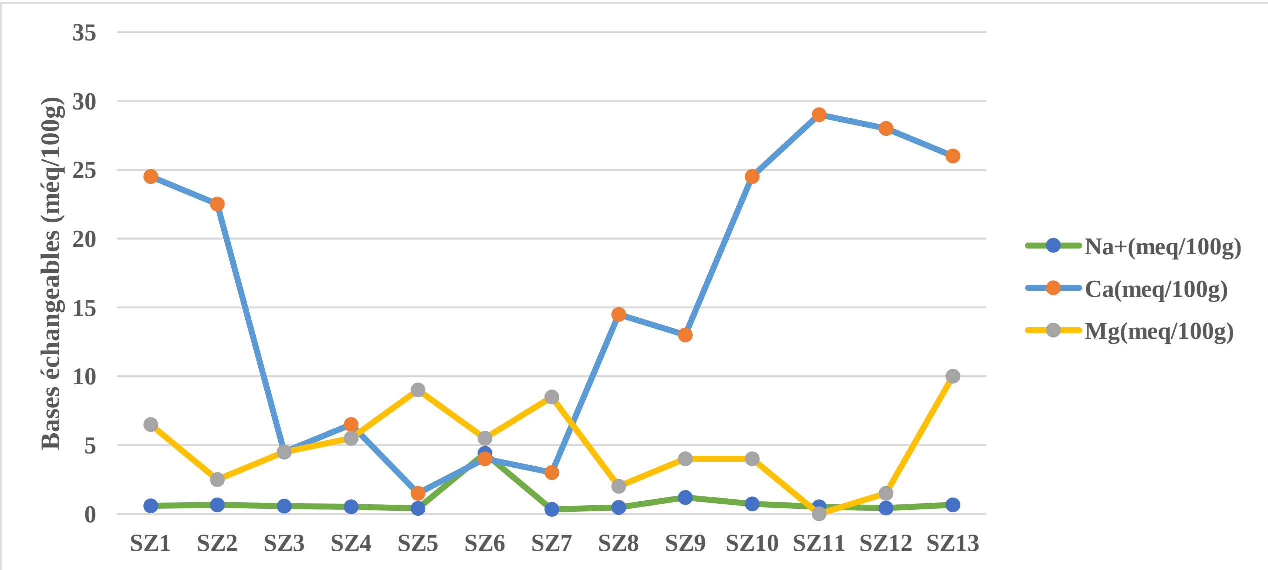

Figure 22. Variations in exchangeable base levels in the soils under study in the fall

2.9 Cation exchange capacity of soils

In the soils under investigation, cation exchange capacity levels are comparatively high in the fall (Fig. 23), ranging from 60.7 meq/100g at site SZ_1 to 6.5 meq/100g at site SZ_7; CEC is higher at depth than at the surface.

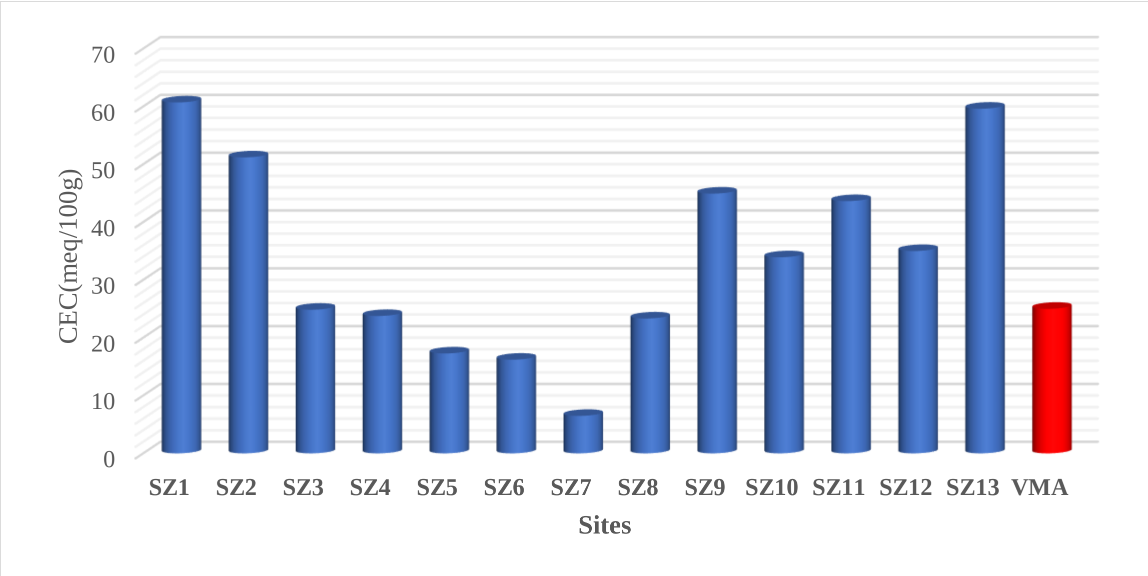

Figure 23. Cation exchange capacity of soils studied

2.10 Statistical analysis

The factorial axes of the soils under study range from 5.41 to 2.80%, or from 41.64 to 21.55% of information on the first two axes, for a total of 63.20% of total variability, according to principal component analysis (PCA). As a result, Table 3's correlation matrix of the variables under analysis depicts the variables' correlation circle on the main plane (F1–F2).

Table 3. Principal factorial axes of the PCA of soils studied

Factor axes	F1	F2	F3	F4
Eigenvalue	5,414	2,802	1,657	0,840
Variability (%)	41,648	21,553	12,749	6,459
% cumulative	41,648	63,202	75,950	82,410

Exchangeable calcium, organic matter, and water pH are all well-represented in the correlation circle and are near axis 1, with a positive coordinate, according to an observation of the correlation circle between the variables and the F1 and F2 factorial planes. Sand percentage and assimilable phosphorus are negative. Variables such as electrical conductivity and exchangeable sodium are close to axis 2 (Fig. 24).

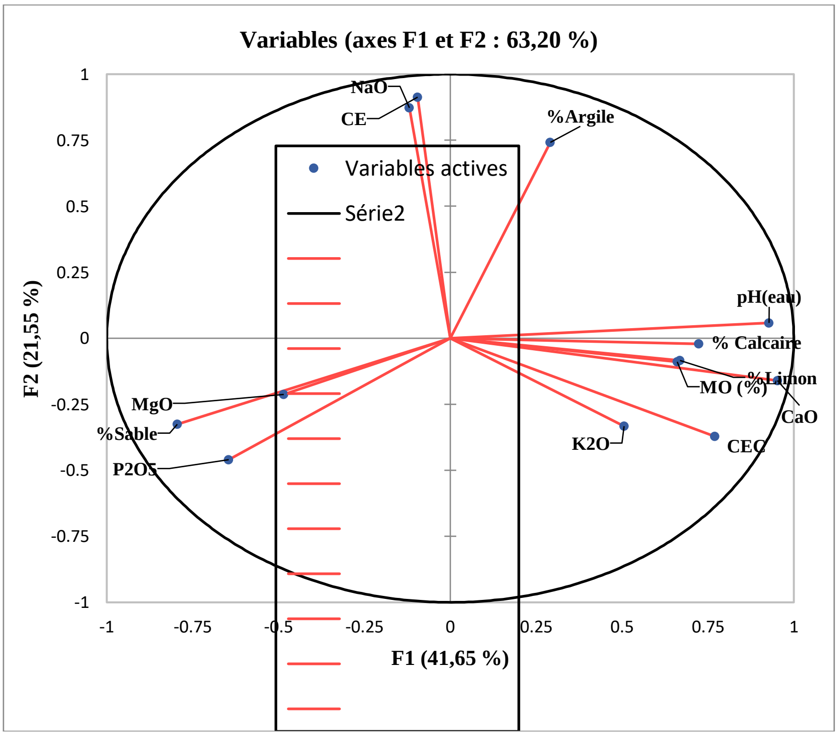

Figure 24. Variables projected into the primary F1 and F2 factorial planes

Figure 25 shows a positive correlation with axis 1 for the variables pH water, % limestone, % silt, CaO and K_2O, CEC and MO, in contrast to MgO, P_2O_5 and sand, which, on the same axis, have a negative correlation with these factors. Conversely, Axis 2 is heavily impacted by CE, % clay, and NaO, all of which are found on positive ordinates. This variable arrangement allows the identification of a first homogeneous group consisting of entire soil limestone and fine materials (silts), which migrate in the same direction as coarse elements (sand).

Three major groups were identified by projecting each person along the F1 axis (Fig. 25):

- Group 1: individuals with high water pH, percentage limestone, % silt, CaO and K_2O, CEC and MO (sites SZ_1, SZ_2, SZ_8, SZ_{10}, SZ_{11}, SZ_{12}, SZ_{13});
- Group 2: individuals with high levels of sand, MgO, and P_2O_5 (sites SZ_3, SZ_4, SZ_5, SZ_7, SZ_9);
- Group 3, which consists of a single site (SZ_6) with elevated EC, clay, and NaO values.

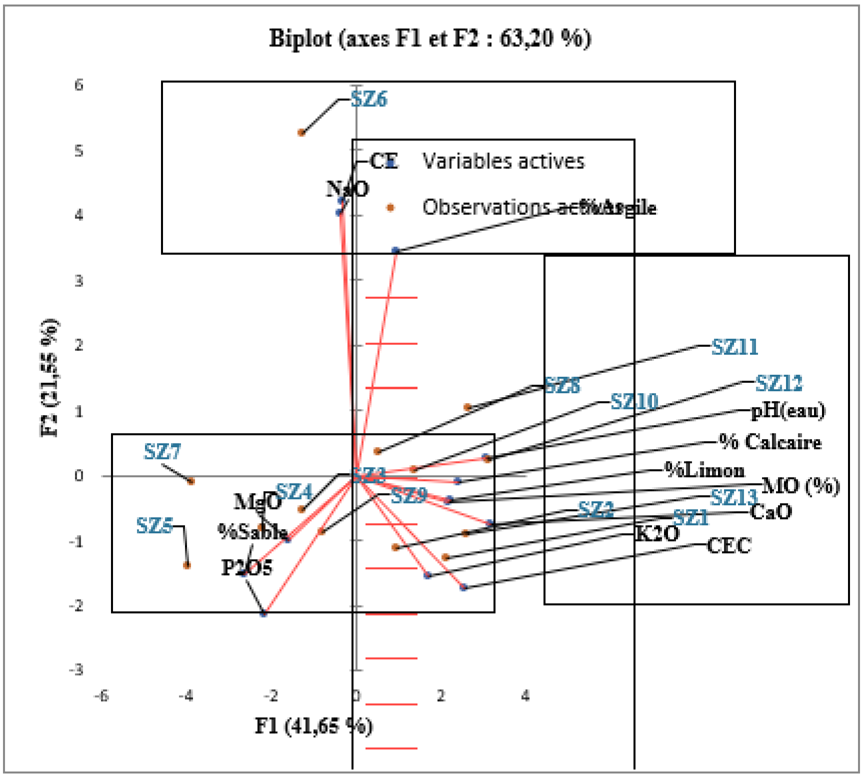

Figure 25. Projection of individuals into factorial planes F1F2

Conclusion

The surface (0-20 cm) and deep (20-40 cm) soils of the Zaër area studied in the autumn show:

- Balanced, earthy clay texture. The predominance of muddy and sandy parts explains the impoverishment of these soils, which is characterized by leaching of nutrients and water, leading to faster drying of the surface when water is completely removed;
- The pH value indicates that the soil under study is moderately alkaline to slightly acidic, with the pH varying between 5.8 and 7.9, which is beneficial for plants to absorb nutrients. These results correspond to those obtained in the spring of the same year;
- measured electrical conductivity indicates that most of the soils studied are at the limits of non-saline soils (EC < 4 dS/m). Total limestone content is less than 3%, indicating that the soils studied have a low limestone content;
- the region's soils are relatively rich in organic matter, allowing for active microbial life. The high organic matter content can be explained by the significant addition of crop residues and the relative massiveness of the soil;
- Base saturation levels and exchangeable calcium are low. However, in the fall, the soils have adequate amounts of calcium and magnesium;
- cation exchange capacity is high, mainly due to good organic matter levels; this is a major asset for agricultural production in the study area;
- the levels of assimilable phosphorus analysed in the soils studied are excessively low, probably due to the low application of phosphorus fertilizers in these soils, given that the phosphorus content of these soils is lower than that found in spring due to the excessive addition of these fertilizers;
- The exchangeable potassium content of the soils studied is considered to be sufficient, so there is no need to add potassium fertilizers. This is mainly due to the nature of the region's soils.

For example, in order to maintain the quality and fertility of soil in the Zaër region and fertilize it to achieve high yields, it is necessary to promote the use of crop residues through the production of manure and various technologies within the reach of most farmers in the region. For sustainable crop production, regular monitoring of soil fertility conditions is necessary to improve the performance of production systems in the region.

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