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Study of the Solonchaks of Northern Algeria by a Geographic Information System (GIS)

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Abstract. The present study consists of a valorization of a pedological database allowing to determine the Solonchaks in the north of Algeria according to the World Reference Base (WRB) classification. We studied the constituents of these Solonchaks by making different thematic maps, for this purpose a geographic information system (GIS) was created. Profiles meeting the definition of Solonchaks will be classified, spatialized in northern Algeria and grouped into reference soils and the creation of different thematic maps. The main results revealed that the Solonchaks of northern Algeria are provided with calcium carbonate ($10 < CaCO3\ (\%) < 60$) and poorly provided with gypsum with an average of 2.5% gypsum. They are also characterized by very high salinity ($15 < EC\ (dS/m) < 40.9$) and relatively high sodicity percentage of exchangeable sodium ($ESP > 15\%$). Statistical analysis revealed that the correlation between the EC-ESP couple is highly significant ($r = 0.62$; $p < 0.01$). Similarly, the correlation between the EC and the Ca++ of the adsorbent complex is negative and significant ($r = -0.34$; $p < 0.05$). The exploitation of the database made it possible to extract 45 profiles corresponding to the Solonchaks. The classification of these profiles revealed 13 references of Solonchaks distributed in the north of Algeria.

Keywords. Solonchaks, WRB Classification, Soil database, Profile reference, Geographic Information System (GIS).

1. Introduction

Soil salinity and alkalinity are a serious environmental problem in the world, they have a negative impact on our soil resources, they contribute to ecological degradation [1].

The evolution of saline soils is mainly dominated by soluble salts, this leads to the degradation of soil properties [2], soil salinity constitutes a major problem for agriculture, because the agricultural potential of saline soils is weak. Salt stress directly affects plant growth by reducing water absorption (osmotic stress) and the accumulation of toxic ions [3].

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Soil salinity also contributes to desertification and causes a significant decrease in plant resistance to various stresses, which causes a regression in agricultural production [4, 5]. Similarly, salinization is a major constraint on a global scale. It affects approximately, 900 million hectares of land, in more than 100 countries are affected by salinization and sodicity [6]. This phenomenon is very common in arid and semi-arid lands, because the salinization process is more marked by high temperatures almost all year round, insufficient or almost absent drainage and low rainfall, insufficient to leach. soluble salts [7]. In these environments, irrigation is crucial for agricultural production, but its poor management can cause adverse effects on soil properties [8] and would therefore constitute a major problem for the sustainability of irrigated land [9].

Furthermore, salinization controls the decision-making process and land use planning strategies, this has a direct effect on effective land management.

In Algeria, much research has been carried out on saline soils[10,11,12,13,14,15]. The various works agree on the fact that they are salty soils by the neutral saline way, the salinity in Algeria is of primary origin and the salinity of the soils is generally accompanied by a sodization of the adsorbent complex. It also emerges from this work that the Solonchaks of northern Algeria can constitute intergrade soils with Calcisols and Gypsisols. Likewise, these Solonchaks have a relatively higher degree of belonging with Calcisols than with Gypsisols.

On the other hand, most of the research on saline soils in Algeria has focused mainly on their saline functioning and the physico-chemical processes that govern them, relegating classification aspects to the background. Therefore, the objective of this study is to exploit a soil database, to extract all the profiles corresponding to the diagnostic criteria of Solonchaks according to the World Reference Base [16] definition, which is an update of the WRB [17]. On the one hand, we studied the constitution of Solonchaks by the realization of various thematic maps, using a geographical information system (GIS) which was created for this purpose. On the other hand, the profiles meeting the definition of Solonchaks will be classified, spatialized in northern Algeria and grouped into reference soils.

2. Materials and Methods

2.1. Materials Used in the Study

The present investigation is an exploitation of a database including soil inventory studies in the northern region of Algeria carried out by Djili [18] and Hadj-Miloud [19] that we exploited. From this database we identified 45 profiles of Solonchaks distributed in northern Algeria (fig. 1).

A Solonchak according to WRB [16] must be characterized by the presence of a salic horizon. This must have over its entire depth:

-An electrical conductivity (EC) of the extract of the saturated paste greater than 15dS /m at 25°C at some time of the year; Where EC of more than 8 dS/m at 25°C if the pH (H2O) of the saturated paste extract exceeds 8.5 (for alkaline carbonate soils) or is less than 3.5 (for acid sulphate soils):

- A thickness of at least 15 cm.
- A product of the thickness in (cm) and the EC in (dS/m) greater than or equal to 450.

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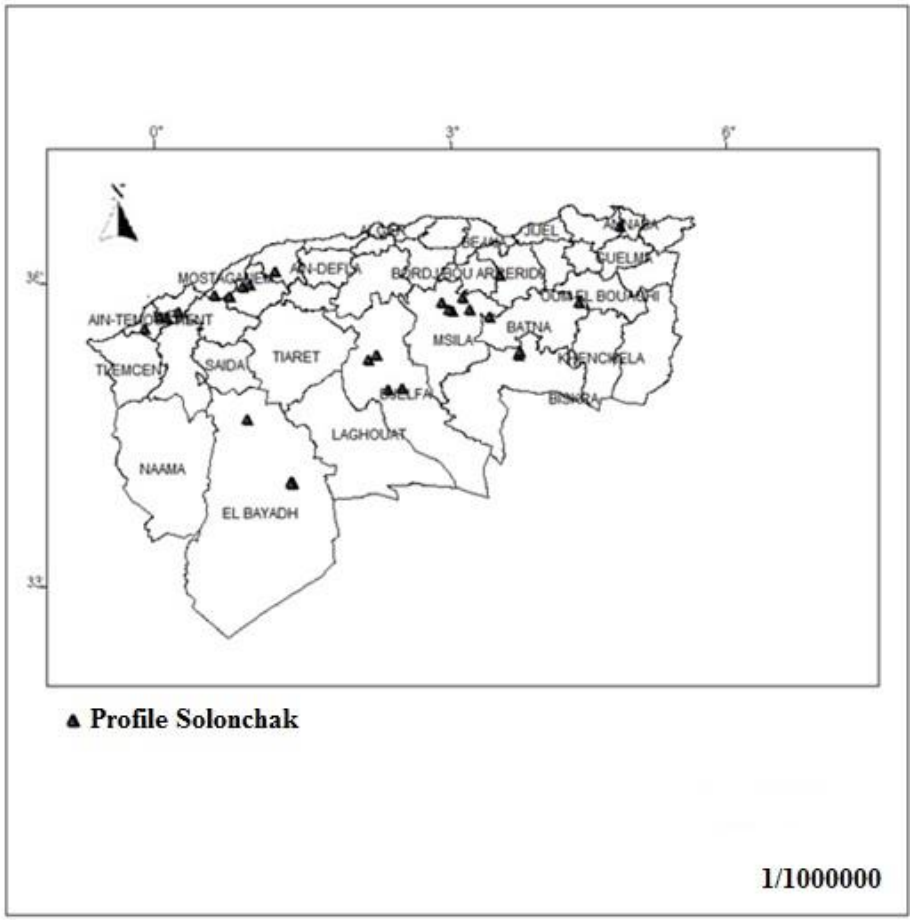

Figure 1. Geographical location of the study zone.

2.2. Methods of Study

The objective of this research consists of an exploitation of a database including soil inventory studies, carried out in the northern region of Algeria. To extract all the profiles corresponding to the diagnostic criteria of Solonchaks according to the WRB (2015), the level of advancement in the classification is based on the data recorded in the database.

First, we extracted 45 reference profiles corresponding to the reference group in question. This was done by querying the database using SQL (Structured Query Language).

In a second step, we proceeded to a localization of these profiles in space to examine their distribution in the northern region of Algeria using a geographic information system (GIS) thanks to the MAPINFO software, which allowed us to create the different thematic maps of the constituents of Solonchaks. The thematic maps that we have produced using GIS are: Clay rate distribution map, CaCO3 rate distribution map, gypsum rate distribution map, salinity maps, pH map, Organic Matter (OM %) distribution, Exchangeable Sodium Percentage (ESP) distribution map, Solonchak classification map and Electrical Conductivity (EC).

For the realization of the GIS we proceed as follows

2.3. Creation of the Table

In the Map-Info software the basic object is the table (fig. 2). Any information layer is associated with one or more tables. The creation of tables within the Map-Info is very simple. The software offers interactive tools for creating tables similar to the classic tools found in most software such as Access.

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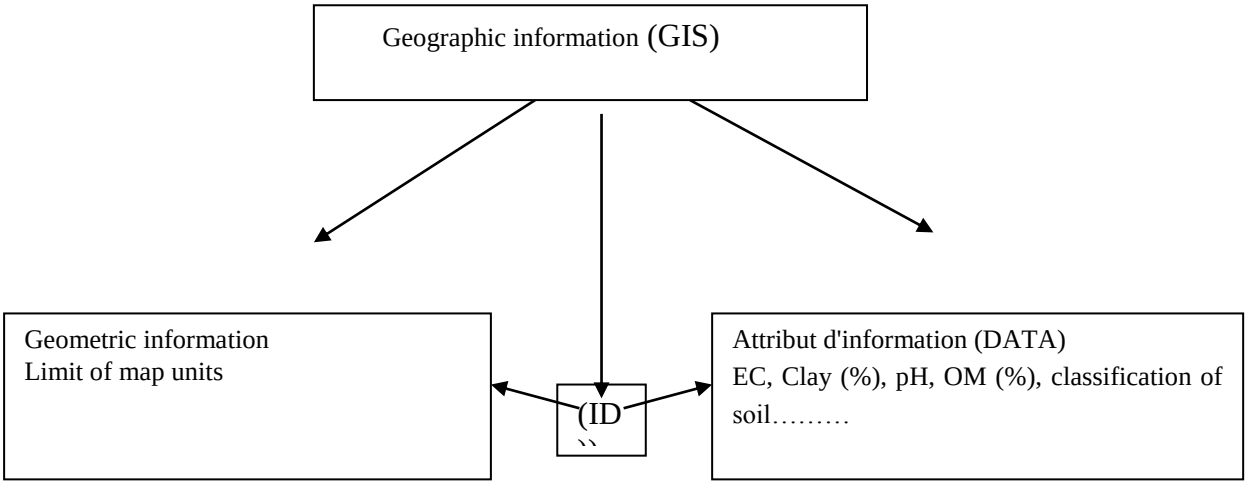

Figure 2. Table structure.

At the logical aspect level of the MapInfo software, there are two file display windows
- Map window: displays geometric data in the form of layers.
- Data window: displays attribute data in the form of a table where the columns represent the fields of information.
- The lines represent the geometric objects, including at least the number of lines corresponding to the number of objects. Our database contains the following information: identifiers, profile numbers, clay (%), EC (dS/m), total calcium carbonate (%), gypsum (%), exchangeable bases (cmol (+)/kg), pH , Organic Matter (OM %) and WRB classification.

3. Results

The descriptive statistics of the constituents of the Solonchak profile are shown in Table 1.

Table 1. Descriptive statistics of Solonchak constituents.

Paramètres	Clay (%)	Calcium carbonate (%)	Gypsum (%)	OM (%)	EC (dS/m)	pH
Maximum	60	52	20	4,54	40.9	8.3
Minimum	7	0,2	0	0,10	15	7.3
Mean	35,89	20,95	2,55	1,60	24.52	7.75
CV (%)	42,93	59,09	145,49	70,62	32	3.74

CV: coefficient of variation.

3.1. Clay

Statistical analyzes of the 45 Solonchaks profiles reveal that the clay content varies between 7% and 60%, with an average of 35.89% (Table 1).
Moreover, these results show that the clay content of the Solonchaks varies from one region to another. This is confirmed by a relatively high coefficient of variation (42.93%) mentioned in Table 1. These results suggest that the majority of the Solonchaks studied are clayey (27 profiles).

3.2. Calcium Carbonate ($CaCO_3$)

Table I shows that the $CaCO_3$ levels fluctuate between 0.2 and 52%. Based on the average values (20.95%) of CaCO3, it turns out that all the profiles are calcareous. However, the distribution of $CaCO_3$ in the 45 profiles is very heterogeneous with regard to the coefficient of variation (59.09%).

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Generally, the majority of Solonchaks in northern Algeria are provided with CaCO3. Calcareous accumulations are frequently associated with those of soluble salts in the soils of northern Algeria [18, 14].

3.3. Gypsum

Table 1 shows that the gypsum levels in the profiles are between 0 and 20%. The average rate of gypsum is 2.55%, this reveals that in general the rates of gypsum are low in the profiles.
Moreover, the coefficient of variation clearly shows that the Solonchak gypsum rates are extremely variable from one region to another (CV=145.49%).

3.4. Organic Matter

According to the statistical results presented in Table 1, the OM rate is on average 1.6%, this indicates that the profiles are moderately rich in OM, with rates varying from 0.1% to 4 .54%. The majority of Solonchaks are poor in MO, its distribution is very heterogeneous from one region to another (CV= 70.62%).

3.5. The Adsorbent Complex

The results of the analyzes of the adsorbent complex are presented in Table 2.

Table 2. Statistical parameters of exchangeable cations (Mg^{++}, Ca^{++}, K^{+} and Na^{+}).

Paramètres	Ca^{++} (%)	Mg^{++} (%)	K^{+} (%)	Na^{+} (%)
Maximum	89,02	63,78	7,59	54,55
Minimum	7,67	2,43	0,2	4,85
Mean	61,46	20,34	1,34	16,86
CV %	25,12	64,30	131,34	45,19

CV: coefficient of variation.

Table 2 and figure 3 show that exchangeable calcium is the dominant cation ($7.67\% < Ca^{++} < 89.02\%$), with an average rate of 61.46%, its variation is moderate (CV = 25.12 %). Exchangeable Mg++ is in second position, its rates vary between 2.43% and 63.78% with a very high variation (CV= 64.30%). It is followed by Na^{+} ($4.85\% < Na^{+} < 54.55\%$) with an average rate of 16.86%, the distribution of exchangeable Na+ is very heterogeneous (CV = 131.34%) (Table 2 and Fig. 3).
K+ is ranked in last position ($7.67\% < Ca^{++} < 89.02\%$) at the level of the cationic filling, with an average rate of 1.34%, its variation is extremely high (CV= 131.34%). This result suggests that the classification of exchangeable bases according to their predominance is of $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$ type.

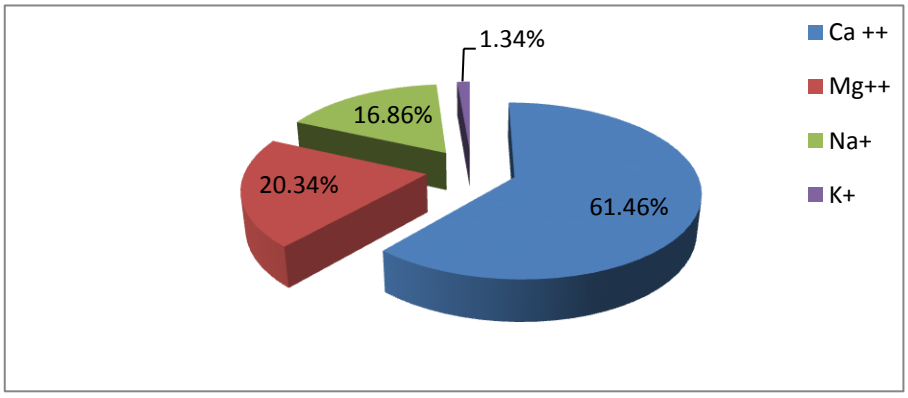

Figure 3. The average distribution of exchangeable cations.

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Solonchaks with low sodicity (percentage of exchangeable sodium (ESP) < 4.84%) represent only 2.2% of the Solonchaks studied. Therefore, these results clearly show that the majority of Solonchaks studied contain very high levels of exchangeable Na.

Analysis of the results (Table 2 and fig. 4) show that the majority of Solonchaks (57%) are sodium (ESP > 15%) (USSL, 1954). These results are consistent with those of the various studies carried out in northern Algeria [14,18,19, 20].

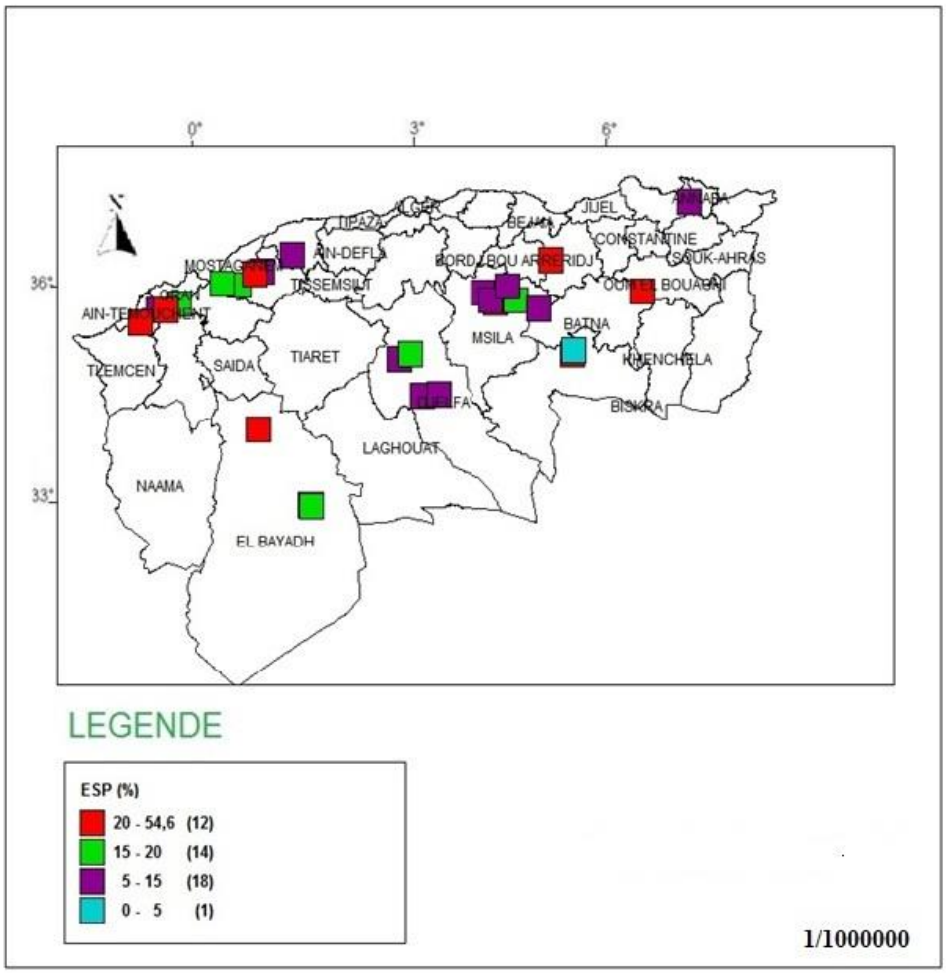

Figure 4. Distribution map of the exchangeable sodium rate (ESP) in northern Algeria.

3.6. Electrical Conductivity (EC)

The distribution of EC (Table 1, figure 5) shows that the profiles are affected by high salinity (15 < EC (dS/m) < 40.9), with an average of 24.52 dS/m . Thus, the variation in salinity is relatively average (CV=32.72%).

In addition, EC values in northern Algeria were subdivided into three intervals (fig. 5).

The EC interval, which varies between 15 and 30 dS/m, represents only 78% of the profiles studied (35 profiles). Furthermore, 18% of the profiles (8 profiles) have EC values varying between 30 and 40 dS/m. They are located in the regions of Rélizane, Bordj Bou Arreridj and Ain-Temouchent. Only 2 profiles have EC values varying from 40 to 50 dS/m, represented by the regions of El-Bayadh and Msila (figure 5). These results clearly show that the soils are extremely saline.

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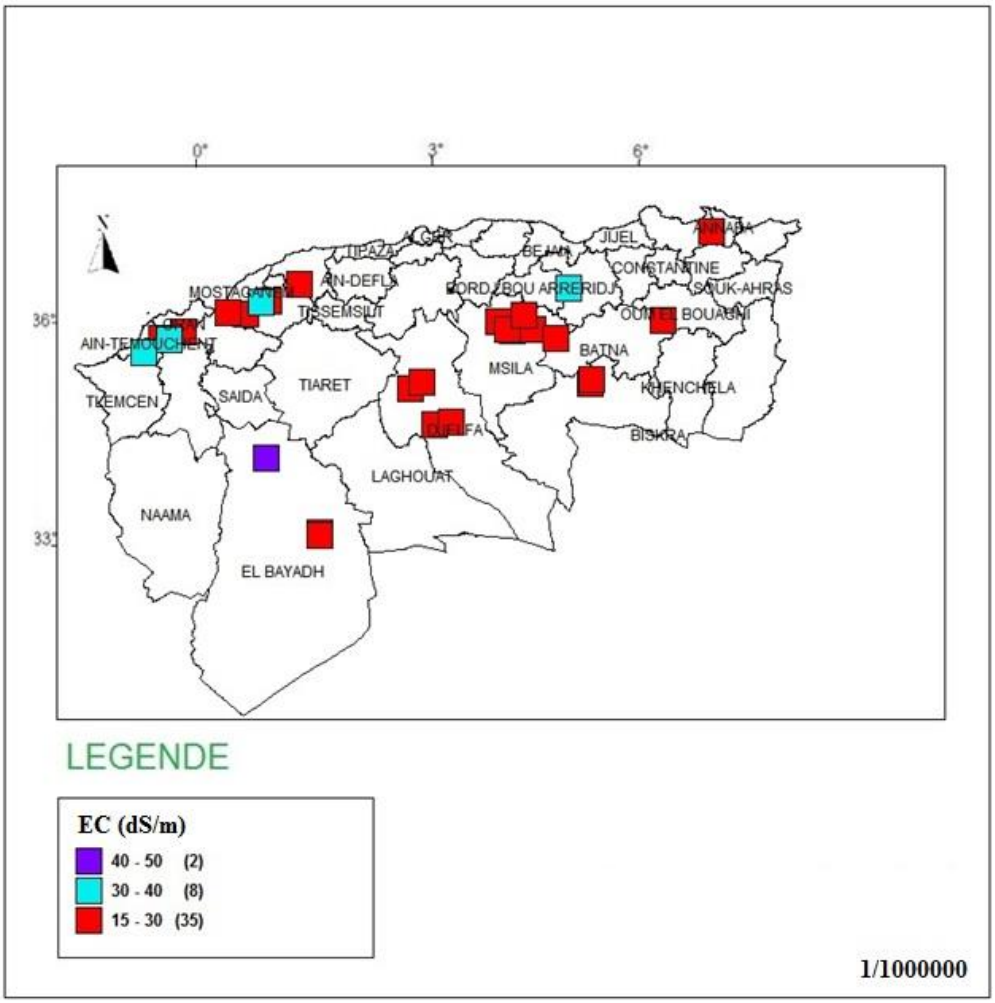

Figure 5. Salinity distribution map of the Solonchaks.

3.7. pH

According to Table 1, the pH values fluctuating between 7.3 and 8.3 in all the profiles, this demonstrates a relatively alkaline soil reaction, with very low variability (CV = 3.74 %).

Furthermore, fig. 6 show that 80% (36 profiles) of Solonchaks have a pH ≥ 7.5. However, 20% of the profiles, i.e. 9 profiles, have pH values between 6.5 and 7.5. These pH values mainly affect the regions of Ain-Temouchent, Djelfa, El Bayadh and M'silla.

These results clearly show that the Solonchaks of northern Algeria are characterized by an alkaline soil reaction.

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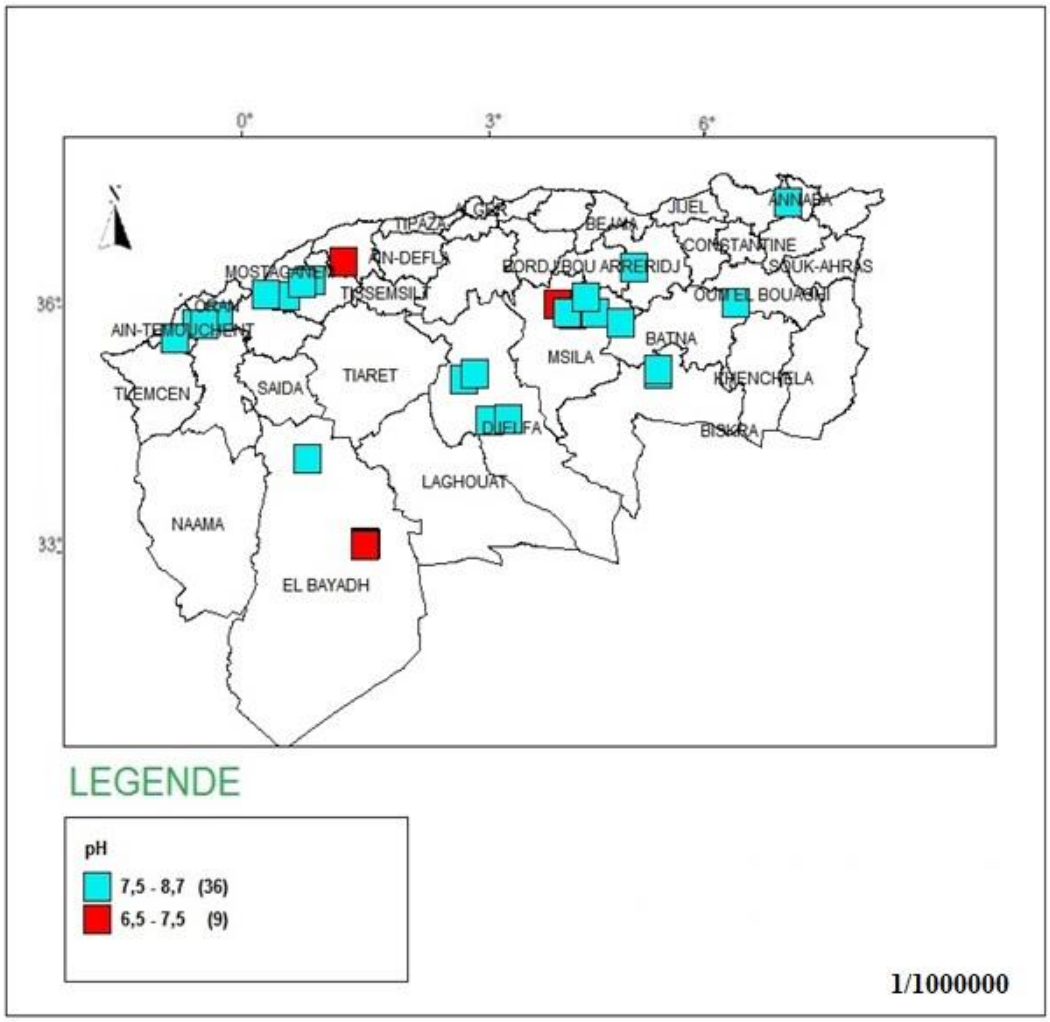

Figure 6. Map of the pH distribution of the Solonchaks in northern Algeria.

The Solonchaks classification: Analysis of the analytical results suggests that the soils studied meet the conditions and diagnostic criteria of the Solonchaks group as defined by the WRB (2015).
The level of advancement in the classification is based on the data recorded in the database.
Nevertheless, we encountered 13 references of Solonchaks distributed in the north of Algeria (Table 3 and figure 7).
Calcic Sodic Solonchaks 35.5%, Calcic Sodic Solonchaks (Clayic) 15.5%, Calcic Sodic Solonchaks (Clayic, Hypersalic), Sodic Solonchaks 11.1% and Calcic Sodic Solonchaks (Hypersalic) 6.6% are the most common in northern Algeria. These references alone represent more than 68.7% of Solonchaks. Gypsic Sodic Solonchaks and Sodic Calcic Solonchaks individually account for 4.4% of Solonchaks. Sodic Solonchaks (Hypersalic), Sodic Solonchaks (Clayic), Gypsic Sodic Solonchaks (Hypersalic), Gypsic Sodic Solonchaks (Clayic, Hypersalic), Calcic Sodic Solonchaks (Humic), and Calcic Gypsic Sodic Solonchaks are the least represented with a frequency of 2.2%.
The location of the Solonchaks in the northern region of Algeria: fig. 7 shows that the Solonchaks of Algeria are located in the regions of Annaba Guelma, M'sila, Biskra, Bordj-Bouarreridj, Batna, Sétif, Khenchela Djelfa, Tiaret (Ksar chellala) Chlef, Relizane, Mostaganem, Mascara, Oran, Ain-Témouchent and El Bayadh.
The analysis of the distribution of Solonchaks in northern Algeria reveals that the spatial distribution of Solonchaks which are provided with gypsum such as Gypsic Solonchaks, Gypsic Sodic Solonchak (Hypersalic) and Gypsic Sodic Solonchak seems linked to climatic conditions. Consequently, they

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have a zonal character. Thus, the Solonchaks which contain fairly high gypsum contents are located only in regions which are characterized by an arid and semi-arid climate.

We can deduce that the spatial distribution of Solonchaks in northern Algeria does not seem to be affected by climate. Indeed, we can meet them in humid regions as well as in semi-arid regions and also in arid regions. This demonstrates the intrazonal character of these soils as mentioned by many authors [18,19,21].

Table 3. Classification and distribution of Solonchaks by region.

Reference	Classification WRB (2015)	Frequencies	Regions
1	Calcic Sodic Solonchak	35,5 %	EL BAYADH, DJELFA, M'SILA, BISKRA, BORDJ BOU ARRERIDJ, CHLEF, ANNABA.
2	Calcic Sodic Solonchak (Clayic)	15,5 %	BISKRA, M'SILA, BATNA, SETIF, ANNABA.
3	Calcic Sodic Solonchak (Clayic, Hypersalic)	8,8 %	RELIZAN, CHELF, SETIF.
4	Sodic Solonchak	11,1 %	BORDJ BOU ARRERIDJ, SETIF, TLEMCEN.
5	Calcic Sodic Solonchak (Hypersalic)	6,6 %	EL BAYADH, M'SILA.
6	Gypsic Sodic Solonchak	4,4 %	AIN-TEMOUCHENT, TLEMCEN.
7	Sodic Calcic Solonchak	4,4 %	DJELFA, M'SILA.
8	Sodic Solonchak (Hypersalic)	2,2 %	AIN-TEMOUCHENT.
9	Sodic Solonchak (Clayic)	2,2 %	CHLEF.
10	Gypsic Sodic Solonchak (Hypersalic)	2,2 %	CHLEF.
11	Gypsic Sodic Solonchak (Clayic, Hypersalic)	2,2 %	TLEMCEN.
12	Calcic Sodic Solonchak (Humic)	2,2 %	M'SILA.
13	Calcic Gypsic Sodic Solonchak	2,2 %	GUELMA.

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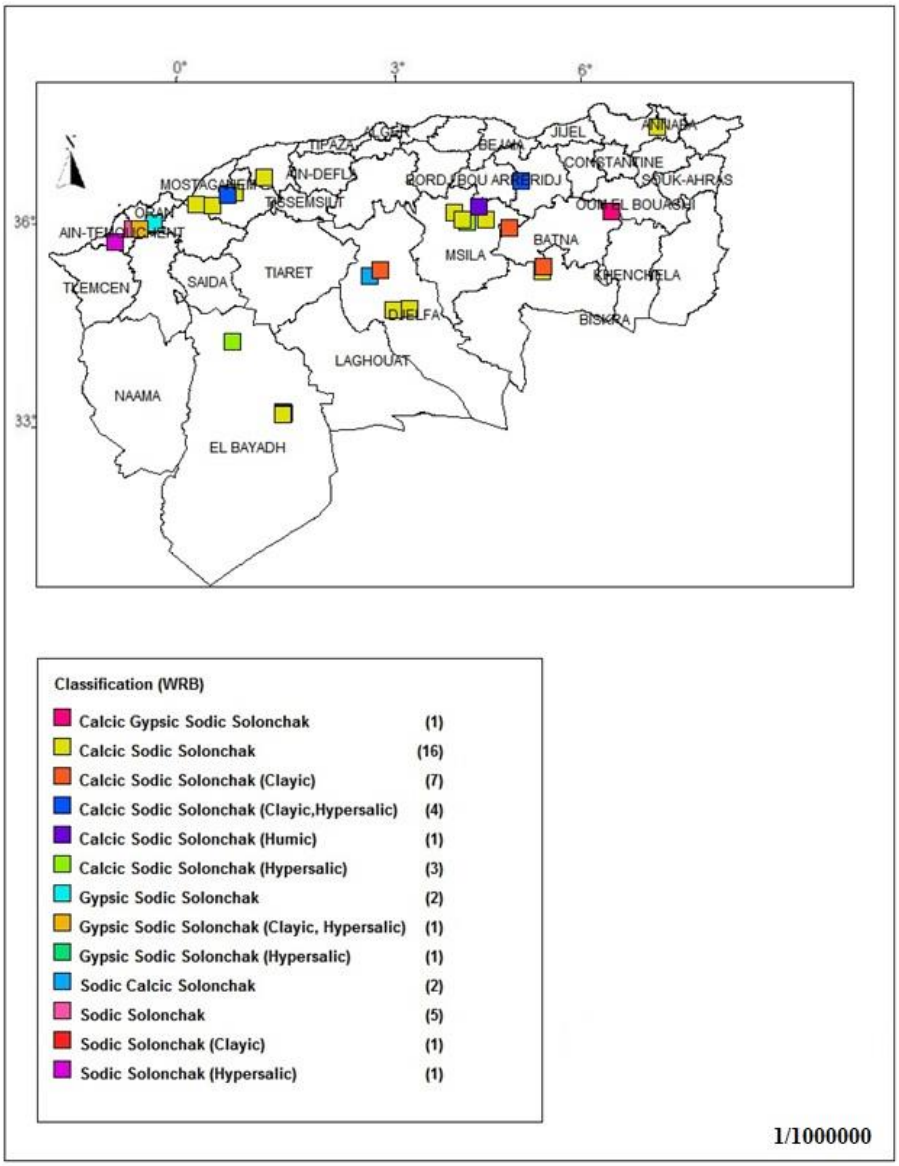

Figure 7. Classification map of the Solonchaks in northern Algeria.

3.8. Relations Between the Ec and the Exchangeable Cations of the Adsorbent Complex

We had recourse to the correlation test, in order to better understand the existing relationship between the EC and the cationic filling of the adsorbent complex. The statistical results of the correlations between electrical conductivity and exchangeable cations are shown in Table 4.

Table 4. Correlations between electrical conductivity and different exchangeable cations.

Relations	R^2	r	DF	α
EC-Na^+	0.38	0.62**	43	0.01
EC- Ca^{++}	0.11	-0.34*	43	0.05
EC-Mg^{++}	0.001	0.03	43	0.05
EC-K^+	-0.009	-0.09	43	0.05

Note. *Significant at probability P < 0.05. ** Highly Significant at probability

P < 0.01, r: coefficient of correlation, R: coefficient of determination, df: degree of freedom.

EC-ESP relation: Statistical results (Table 4) reveal that the correlation between the EC-ESP couple is highly significant (r = 0.62; p <0.01). This result is well illustrated by fig. 8 which clearly shows that the increase in EC is accompanied by an increase in the Na^{+} exchangeable at the level of the adsorbent complex. The regression equation obtained is as follows: ESP = 0.60EC + 2.32.

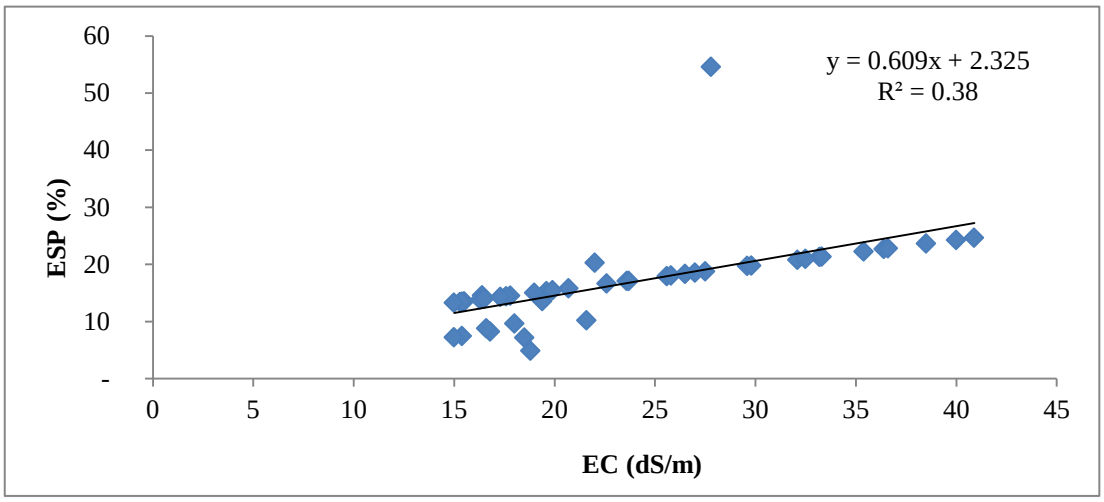

Figure 8. Relationship between EC and ESP.

Relationship between EC-Ca^{++} Exchangeable: statistical results show that the relationship between the EC-Ca^{++} couple is significant
(R = - 0.34; p <0.05) (Table 4). This statistical relationship is proportionally reversed, this means that the increase in electrical conductivity is followed by a decrease in the percentage of Ca^{++} exchangeable on the adsorbent complex. This is illustrated by figure 8.
The linear regression equation is type Ca = -0.66EC + 78.57.

3.9. Relationship Between EC-Mg and EC-K

Statistical results have shown that this does not seem to have a significant effect on the exchangeable cations Mg^{++} and K^{+}, as indicated in Table 4.

4. Discussion

Among the soils studied certain Solonchaks contain relatively high levels in gypsum such as the Solonchak gypsic their distribution is affected by the climate. In addition, the greatest extensions of gypsum accumulations have been shown to be located in areas with an average precipitation between 100 and 250 mm [22, 21, 23]. However, 84 % of the soils studied contain gypsum rates between 0 and 5 %. The very low gypsum rates (content between 0 and 5 %) are the most frequent in the soils of northern Algeria regardless of the position of the horizon in the profile. We can say that the Solonchak gypsic has a zonal character.
In addition, the soils studied have high CaCO3 levels such as Calcic Solonchaks, 84 % of profiles have CaCO3 rates between 10 and 60 %.
In Algeria, the accumulations of salts associating with that of CaCO3 are very frequent, we can meet them both in arid and semi arid areas [10] and in wet and subhumid areas [23]. As a result, the qualifier Calcic is the most dominant.
However, high CaCO3 rates of Solonchaks have a direct effect on the cationic garnish, because the exchangeable calcium constitutes the dominant cation at the level of the adsorbent complex (61.46 %).

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The majority of Solonchaks in northern Algeria are clayey (60 %). Indeed, the most clay Solonchaks coincide with those who are the most salty. Has been shown by many authors that the clay texture is most affected by salinity, because of its water retention which is important [23].

The soils studied are affected by a very high salinity (15 < EC (dS/m) <40.9). On the one hand, the extreme values of salinity (EC > 30 (dS/m)) seem to be located in the regions marked by rainfall insufficiency such as the regions of Rélizane and Biskra. On the other hand, the highest values of this have a direct effect on the strong values of the ESP, because 57 % of Solonchaks are sodium (ESP > 15 %) [24]. The analysis of the results shows that the majority of Solonchaks (57 %) are sodium (ESP > 15 %) [24]. The relationship between ESP and salinity is highly significant (r = 0.62; p <0.01), this result means that there is a tendency to increase the ESP when the EC increases. We can say that salinity is accompanied by a sodicity. This result combines well with the various works carried out in northern Algeria [14, 20, 14]. As a result, the qualifier Sodic is predominant compared to other qualifiers selected for the classification of Solonchaks. In addition, the increase in Na+on the adsorbent complex is done at the expense of Ca^{++} , statistical analysis has shown that the relationship between Ca^{++} exchangeable and salinity is significant and negative (R = -0.34; p <0.05). So, this relationship is proportionally reversed, this is explained by the fact that when salinity increases there is an increase in sodium on the adsorbent complex to the detriment of the Ca^{++} exchangeable, as mentioned in the study by Touaf (2002). Be that as it may, the analysis of the Adsorbent complex has shown that exchangeable calcium remains the cation dominate with regard to other cations of the Adsorbant complex (7.67 < Ca^{++} (%) < 89.02). This could be explained by the fact that the soil is CaCO3.

In addition, most of the Solonchaks have pH values between 7.5 and 8.7. This demonstrates the alkaline character of Solonchaks from northern Algeria.

Finally, the making of the Solonchaks classification card in northern Algeria allowed us to identify 13 references from Solonchaks. This card revealed that the qualifiers Gypsic, Calcic and Sodic are the most frequent of Solonchaks in the north of Algeria. On the other hand, the hypersalic qualifiers and Clayic are the least represented.

However, we would like to specify that certain Solonchaks among those studied, can possibly constitute intergrades solonchak-calcisol, because the latter represent 29.9% of Solonchaks in northern Algeria as was shown by Hadj Miloud [13].

In general, the study of 45 Solonchaks profiles revealed that the spatial distribution of Solonchaks in northern Algeria does not seem to be linked to the climate, this demonstrates the intrazonal character of these soils.

Conclusion

The main results obtained have shown that Solonchaks in northern Algeria are filled with calcium carbonate (10 < CaCO3 (%) < 60). Therefore, Ca^{++} constitutes the predominant cation of the Adsorbent complex, it is followed by Mg^{++}, Na^{+} and K^{+} which is classified in last position.

However, gypsum rates are relatively low for the majority of Solonchaks (0 < gypsum (%) < 60) with an average rate of 2.5 %. The highest values of gypsum are weakly represented by Solonchaks in northern Algeria.

In addition, the majority of the soils studied are clay (7 < clay (%) <60) with an average of 36%, the highest values of salinity coincide with the highest clays.

However, the Solonchaks studied are marked by a very high salinity (15 < EC (dS/m) <40.9). The most important salinity values (EC > 30 (dS/m)) are identified in regions marked by rainfall insufficiency in this case the region of Rélizane and Biskra. The range of this most represented Solonchaks is between 15 and 30 dS/m. Obviously, the highest values of this coincidence with the strong ESP values, because 57 % of Solonchaks are sodium (ESP > 15 %). In addition, the values of the pH (7.3 <pH <8.3) in all profiles, demonstrate the alkaline nature of these Solonchaks.

In addition, the classification of 45 profiles highlighted 13 Solonchaks references distributed in northern Algeria, the most frequent are Calcic Sodic Solonchak (35.5 %), Calcic Sodic Solonchak

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(Clayic) (15.5 %), Calcic Sodic Solonchak (Clayic, Hypersalic) (8.8 %), Sodic Solonchak (11.1 %) and Calcic sodic Solonchak (Hypersalic) (6.6 %). In general, these references are located in the regions of El Bayadh, Djelfa, M'Sila, Biskra, Bordj Bou Arreridj, Batna and Annaba.

On the other hand, the frequencies of the other references of the Solonchak group vary between 2.2 and 4.4%, so are the least represented references, they are identified in the regions of Ain-Temouchent, Tlemcen, Chelef, Batna and M'Sila. So we can say that the Solonchaks in northern Algeria are very diverse.

However, the reliability of these results remains linked to the quality of the database used.

The geo-referencing of all Solonchaks on the Algerian map has shown that the spatial distribution of this reference does not seem to be linked to the climate. This result shows the intrazonal character of the Solonchaks of Algeria. However, the Solonchaks gypsic are located in arid and semi-arid zones which reflects the zonal character of this reference. However, this character would be much more linked to the presence of gypsum than to the salinity of the reference.

The statistical analysis revealed that the correlation between the EC-ESP couple is highly significant ($R = 0.62$; $P < 0.01$). Likewise, the correlation between EC-Ca^{++} of the adsorbent complex is negative and significant ($R = -0.34$; $P < 0.05$).

We conclude that the increase in salinity is accompanied by a decrease in the percentage of Ca^{++} exchangeable on the adsorbent complex for the benefit of the Na^{+} exchangeable.

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