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DISTRIBUTION OF SOME PEDOLOGICAL CHARACTERISTICS FORMED IN MEDITERRANEAN CLIMATE. EXAMPLES FROM THE SOILS OF NORTHERN ALGERIA

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Introduction

The north of Algeria is under the influence of Mediterranean climate. This influence is gradually attenuated from north to south of the country. Analysis of different researches, in particular those that prepared rainfall maps of Algeria (Gaussen et al., Bagnouls, 1948; Gaussen and Vernet, 1948; Aissani et al., 1993) indicate a clear tendency to the aridity of the environment moving from north to south. The same tendency exists also from the East to the West, on the most northern fringe of Algeria.

The distribution of the mean annual rainfall through the north of Algeria is similar to a succession of biogeographical and physiographical domains which are homogeneous (Barry and al., 1974) from north to south, but also from the east to the west of the Algeria.

Many researches (Gauer et. al., 1991; Take, 1992; Toit and Preez, 1993) showed that several pedological features are in narrow relationship with the environmental factors, particularly with the climate in which the soils develop. Following this context, the pedological map of Algeria at scale 1:500,000 (Durand, 1954) reveals that the spatial distribution of the great pedological units has a strong similarity with that of the climatic and biogeographic domains.

Focusing on the cartograms of pedological classes of 5 features (calcium carbonate, gypsum, clay, organic matter and ESP), Djili (2000) showed a progressive variation of their rates and values in space and in the profiles studied in the dry to the wet environments of north Algeria. This result is confirmed by Djili et. al. (1999) and Djili and Daoud (2000), which showed that the calcareous, gypseous, clayey, sodic and organic matter average profiles differ according to their location in arid, semi-arid or subhumid/humid climate. They also put in evidence that there is mainly the mean annual precipitation that controls the space variability of these pedological characteristics.

The main objective of this study is to determine the upper and lower isohyets in which calcium carbonate ($CaCO_3$), gypsum, clay and organic matter rates evolve. In addition, it was decided to examine how the values of the exchangeable sodium percentage (ESP) and the pH are best expressed in the soils located in the north of Algeria.

Material and Methods

The necessary data for the study were extracted from an existing pedological database

(Djili, 2000) without prejudging position of the samples in the profile. The choice for the characteristics of this study is justified by the fact that they are the main criteria when establishing soil-mapping units and they play a great role in the morphology and the agronomic properties of the soils.

The aim of the study was to determine in which rainfall section each one of these characteristics is best expressed, in other words, between in which isohyets its stronger rates or values are most frequent. To achieve this, we studied the distribution rates and values of each one of them according to average annual rainfall. The description of the cloud points and the fitting polynomial will permit to propose the upper and lower rainfall limits considered as pedological domain of each parameter.

Results and Discussions

Characteristics of the studied data

First, we sought the conformity between the rainfall database and those of Gaussen and Bagnouls (1948), Gaussen and Vernet (1948) and Aissani et al. (1993). For that, we correlated the mean annual rainfall data with longitude and latitude. The results (Table 1) indicate that the correlation is very highly significant ($p < 0.0001$) with the correlation coefficients of 0.30 and 0.78 respectively for longitude and latitude. As confirmed also in previous studies, the result suggests that rain decrease from north to south and east to west.

Table 1. Statistical results of rain quantity and longitude and latitude

		Longitude	Latitude
Rain	r	0.302	0.789
	p	< 0.001	<0.001
	Sample number	4088	4088

Second, the statistical analysis revealed that except for the pH, whose coefficient of variation (C.V.) is relatively low (6,65%), all other parameters vary strongly in space. The standard deviations and the range (difference between the maximum and minimal value) confirm this finding.

Table 2. Statistical results of parameters

Parameters	Numbers	Minimum	Maximum	Average	Standard deviation	C.V.%
Rain mm	4088	130.00	1000.00	494.92	214.92	43,4
$CaCO_3$ %	3136	10	95.00	20.15	15.92	79
Gypsum %	494	10	96.00	10.49	17.47	166,5
Clay %	2544	20	83.00	34.20	14.94	43,68
O.M. %	2523	02	9.98	1.47	1.40	95,2
ESP %	1745	03	90.73	7.38	11.20	151,76
pH	3453	4.90	9.00	7.7119	5131	6,65

Then, we correlated each parameter with the average annual rainfall. The results (Table 3) indicate that even if the correlation is relatively weak, there is a diminution of the gypsum, calcium carbonate, organic matter accumulation rates, pH and exchangeable sodium percentage values when rainfall increases. On the other hand, the clay rates tend to increase. These low values of the correlation coefficients are explained by the fact that the local pedogenesis factors of the environment have also a strong influence on these parameters.

Table 3. Statistical results of parameters and rain quantity

		$CaCO_3$	Gypsum	Clay	O .M.	pH	ESP
Rain	**R**	-.304	-.136	099	-.085	-.334	-.260
	P	<0.001	<0.003	<0.001	<0.001	<0.001	<0.001
	Numbers	3136	494	2544	2523	3453	1745

The search for a better adjustment as well as the cloud points analysis (Figures 1-6) confirm this tendency and suggest in addition that there are rainfall domains in which each one of these parameters is best expressed. In the discussions that follow, we consider successively the case of each characteristic.

Rainfall influence on the parameters

Calcium carbonate

Calculations were made on 3,116 data couples and showed that the coefficient of correlation is negative and equal to 0.30. This value indicates that the correlation between the calcium carbonate rates and the rainfall levels is statistically significant ($p < 0.001$). The analysis of Figure 1 indicates clearly that the $CaCO_3$ rates decrease when the annual average rainfall increases. Nevertheless, the points cloud of this figure state also that the majority of the strongest calcium carbonate rates in the soil are situated in the rainfall section delimited by isohyets 270mm and 500 mm.

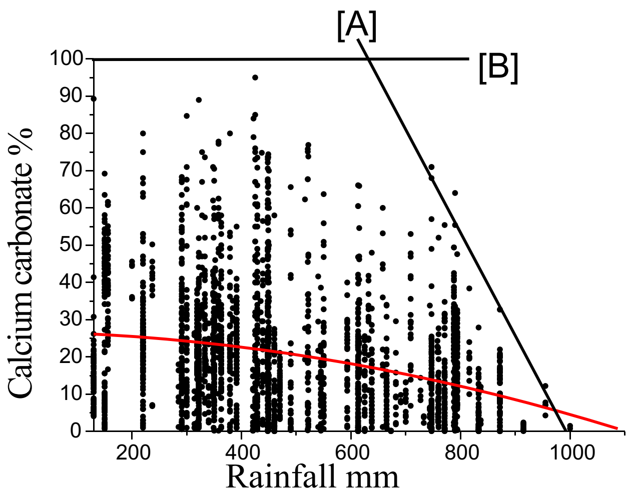

Figure 1. Relation betwen rainfall and calcium carbonate

However, the curvilinear adjustment indicates that the effect of the rainfall heights on the decrease of this parameter rates appears essentially only from 300/350 mm.

Figure 1 shows also that the majority of points does not come out of a very precise zone of the diagram delimited by axes of the abscissa, of the ordinate and lines [A] and [B]. Line [A] means that we cannot have more than 100% of calcium carbonate. Line [B] indicates that the probability to have more calcium carbonate than " rain*a + b " is nearby to zero. It means that if the bedrock is not carbonated, we can have the $CaCO_3$ rates equal to zero whatever is the rainfall level. On the other hand, even on carbonated bedrock, if the rain is significant, the soil cannot be calcareous. It is therefore a "hemi-correlation " which is justified by the fact that, even if the points are not aligned, they do not come out of a precise zone of the diagram.

Gypsum

Calculations done on 494 samples showed that the linear correlation coefficient is statistically significant even if the relationship is relatively weak (-0,135). The linear regression line (Figure 2) confirms the tendency to the reduction gypsum rates when the rainfall increases. The shape of the points cloud confirms it but reveals, moreover, that the soils can be differently endowed with gypsum for the same rainfall. This phenomenon could be due to the effect of the pedogenesis factors of local environment (gypseous bedrocks, topography), that are favorable to the gypseous accumulation.

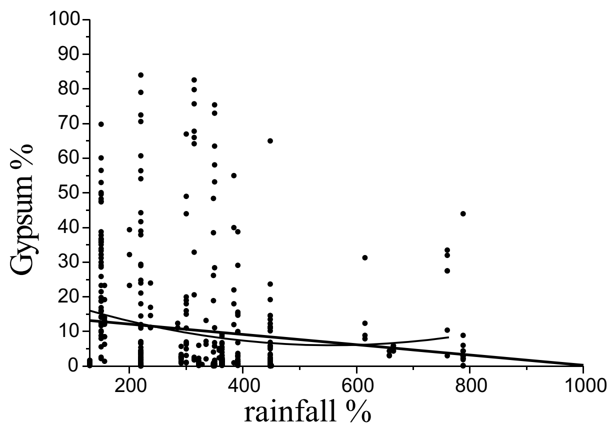

Figure 2. Relation betwen gypsum rates and rainfall

The points cloud of Figure 2 indicates also that the gypseous soils domain (strong gypsum accumulation in soils) is in the lower rainfall section of less than 400 mm, and that it oscillates preferentially between 200 and 300 mm. Figure 2 reveals also that away from 450 mm, the effect of rain on accumulation of gypsum in the soil is very limited.

However, while considering the equation of linear regression (y = 15,5 - 0,015x), we found out that from 1,010 mm annual rainfall (the value 1,010 mm is obtained while assigning to (y) zero value), soils are completely deprived of gypsum.

Knowing that the gypsum rates are best expressed in the arid domain (approximately 250 mm) but cannot exceed the threshold of the 100%, we could draw the line (100%gypsum, 250 mm; 0%gypsum, 1010 mm) whose equation is of type:

$$\text{gypsum \%} = 132 - 0{,}130 \text{ rainfall in mm.}$$

This line permits to calculate the probability so that a content of gypsum goes beyond a threshold corresponding to rainfall data. It is worth statistically 3 (points above the line)/494 (a total number of points) either 0,006. This probability is thus extremely weak. For example, it is not very probable, for Algeria, to have 40% gypsum in soil when rainfall exceeds 700 mm.

Organic matter

The statistical tests done on 2,523 data couples indicate that the correlation is significant even if the relation is very weak (r = -0,08). However, the points cloud and the tendency curvilinear curve (Figure 3) suggest that generally, the best provided soils with organic matter are located principally between isohyets 400 and 600 mm. Out of this precipitation interval, there is a progressive decrease of the organic matter accumulation rate.

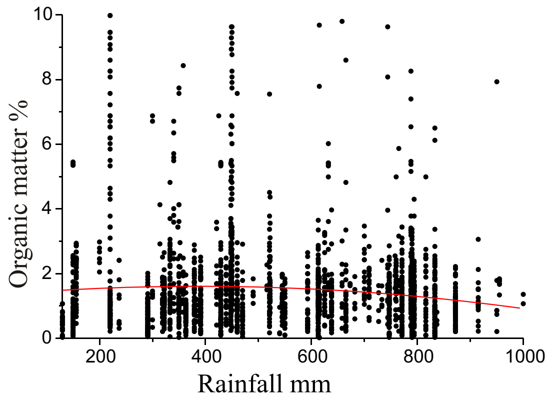

Figure 3. Relation betwen organic matter and precipitation and O.M.

This reduction is distinctly more marked in the rainy zones (rainfall > 600 mm) compared to those drier (rainfall < 400 mm). This phenomenon could be due to the quality and the quantity of vegetation, but also to other factors, as the presence of large calcareous bedrock that favours the conservation of organic matter in soils.

Exchangeable sodium percentage (ESP)

ESP values are strongly influenced by the rainfall. Indeed, the tests done on 1,750 data couples the ESP-rainfall levels showed that the correlation coefficient is statistically significant (r = -0,26). It means that the ESP values decrease when rainfall increases. The curvilinear regression curve (Figure 4) confirms it.

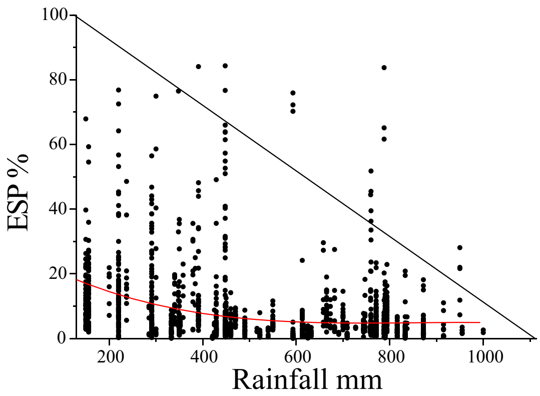

Figure 4. Relation betwen ESP and rainfall

The analysis of this figure indicates that the strongest ESP values are located in the rainfall section lower than approximately 450 mm. It also reveals that at any rainfall intensity, we can find strong as well as low ESP values. This phenomenon is also explained by the particular pedogenesis factors of the local environment (*i.e.* salts accumulation, topography, and drainage).

However, the curvilinear regression curve (Figure 4) shows also that the rainfall influence on ESP values is strongly attenuated from 400/500 mm (r = - 0.30). This result suggests that isohyet 450 mm constitutes the northern limit of the domain of the strongly sodic soils. By considering the linear regression equation, we figured out that the values of ESP are equal to zero when rainfall reached 1,115 mm.

The ESP rates cannot exceed 100%, so we can draw the line whose equation is:

$$ESP = 100 - 0{,}089 \text{ rainfall (mm)}$$

This line indicates the probability that ESP does not exceed some threshold value for a given rainfall. This probability is 23 (number of points above the line)/1745 (total number of points) that is equal to 0,013. It is thus very weak. This line can have a practical interest for the setting new data in database. For example, in Algeria, it is very improbable to find soils with value ESP equal to 38 or more when the rainfall reaches or exceeds 700 mm.

pH

The calculations were done on 3,453 pairs " pH-rainfall " indicate a decrease of the pH values when rainfall increases (r = -0,33). This relation is statistically significant (p <0.001). The analysis of Figure 5 confirms this tendency to the pH values reduction when the rainfall augments.

Points cloud of this figure suggests to take account four distinct sectors according to the neutral pH and when rainfall equals to 600 mm. The two upper quarters of this figure reveal that the alkaline pH is distributed in the dry areas as well as in the humid ones.

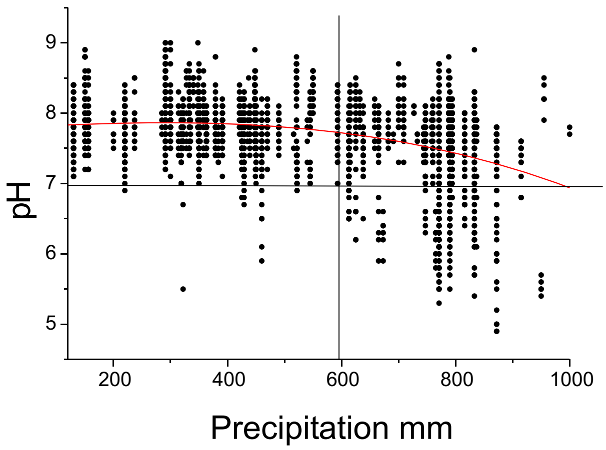

Figure 5. Relation betwen pH and raifall

In the dry areas, the high evapotranspiration and low precipitation are insufficient to acidify soils, while in the humid domains, there are probably the pedogenesis conditions of the local environment (topography, low internal drainage of soils) which prevent the leaching of salts (especially calcium carbonate) and, therefore, the pH reduction.

In the left inferior quarter, there is only very few points, which are located around isohyet 400 mm. It means that, if the pedogenesis conditions are assembled (acidic and filterable rocks for example), we could find acid soils even if it rains a little more than 400 mm. On the other hand, it is in the right inferior quarter that are mainly localized the acidic soils. We can thus suggest that isohyet 600 mm constitutes the upper limit of acidic soils appearance.

From this limit, acid soils become more and more frequent and their pH is continuously low. This phenomenon is confirmed by the tendency curvilinear curve (Figure 5), which indicates a clear diminution of the pH values starting from a rainfall values of 500-600 mm. These results are concomitant with the space distribution of calcium carbonate, gypsum and ESP. They indicate that leaching out from the soil profile of soluble salts is responsible for the soil alkalinity and this becomes effective only from isohyet 600 mm and beyond.

Clay

Calculated for 2,539 samples, the correlation between clay rates and average annual rainfall is statistically significant ($r = 0{,}14$; $p < 0.001$) even though the relation is very weak. Indeed, the points cloud of Figure 6 does not reveal any clear tendency to increase rate of clay accumulation from dry to humid climate environments.

It also shows that the clayey soils can be located indifferently in any rainfall section and that strong clay rates are dependent on the local conditions of the pedogenesis factors. However, it also reveals that the frequency of clayey soils is preferentially localised in subhumide/humide climate.

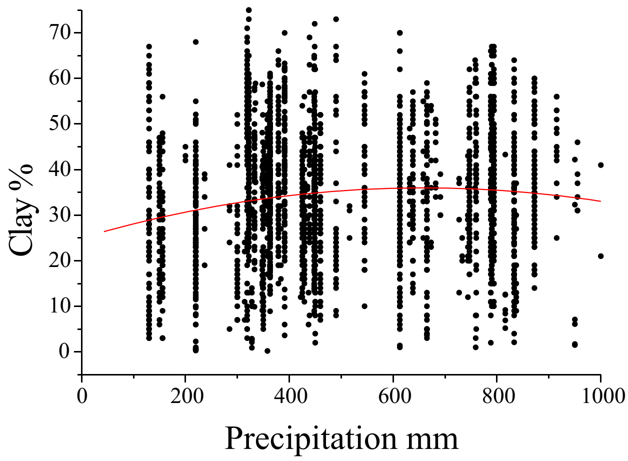

Figure 6 : Relation between clay rates and rainfall

The linear regression (Figure 6) confirms it. This phenomenon is also confirmed by the tendency curvilinear curve that reveals moreover, the existence of two distinct environments divided by isohyet 300 mm. In the first (rainfall < 300 mm), the average rates of clay in soils are lower than 30%. In the second (rainfall > 300 mm), they are higher than 30%.

Therefore result suggests that Algeria's soils are subdivided in two great domains of alteration. In the first, which is in the dry zones, alteration is weak and the soils are relatively provided with little clay. In the second domain, which includes the fringe that extends from the Mediterranean to the steppe area, alteration is stronger and clay increase is evident. These results confirm the findings of Pedro since 1984.

Conclusions

This study led made it possible to highlight rainfall domains of the studied parameters. Using the results obtained we could propose the pedological domains of Algeria and their relationship with the mean annual precipitation as shown in the following Figure 7.

Appart from the particular conditions of the local pedogenesis, if the rainfall is significant, the soils tend not to be calcareous or gypseous even if the bedrock is calcareous or gypseous. However, the soils, which are most provided with calcium carbonate, are located between isohyets 270 and 500 mm while those which are with gypsum are situated preferentially between 200 and 300 mm. This low difference between the two domains could be due to the fact that the gypsum is more soluble than calcareous formations and thus more easily mobilizing by weak rainfall.

The soils best provided with organic matter are located between isohyets 400 and 600 mm. This rainfall section coincides in part with the domain of the calcareous soils, which are favorable to the conservation of organic matter.

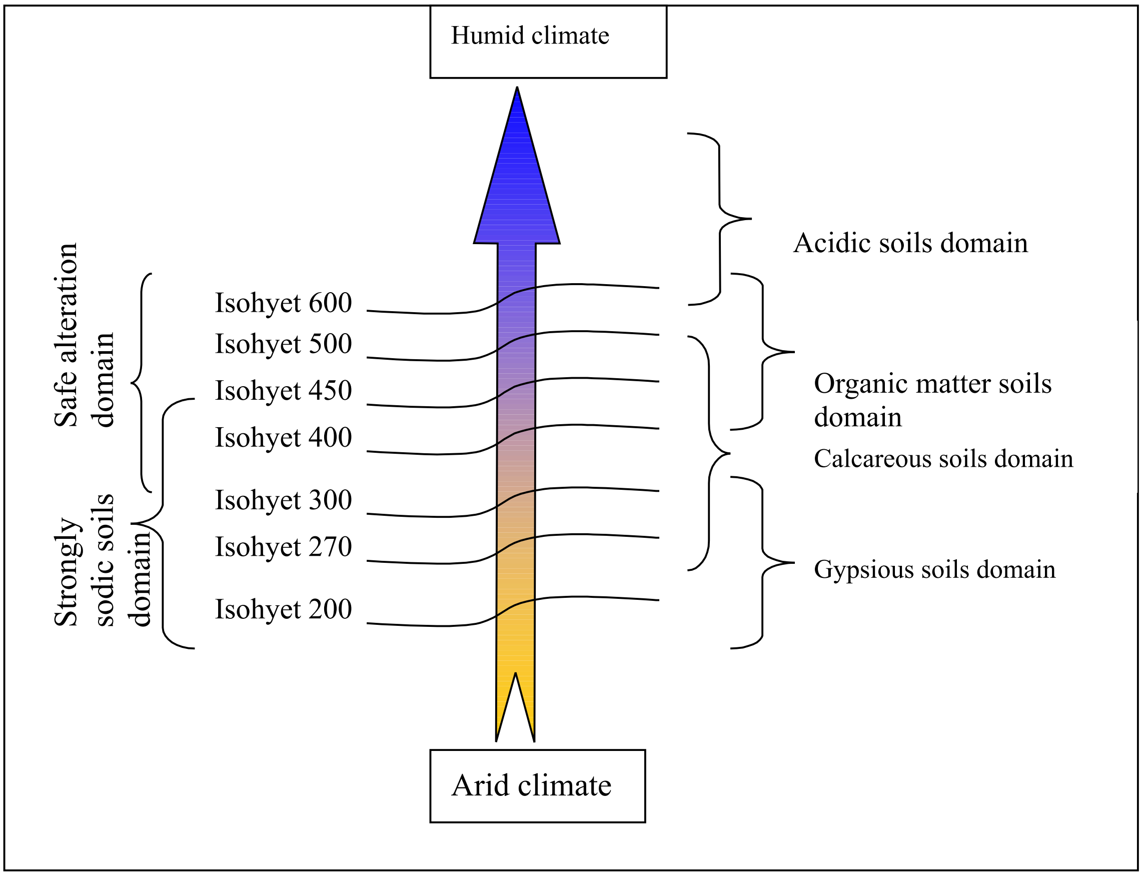

Figure 7. Pedological domains according to the annual rainfall

The isohyet 450 mm seems to be the superior limit of the strongly sodic soils. Indeed, beyond this limit, the sodic soils are rare and found only in some particular conditions. The isohyet 600 mm constitutes the superior limit of appearance of acidic soils. Below this limit, the acidic soils are rare even if the bedrock is not calcareous.

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