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Effects of Maghnian Bentonite on Physical Properties of Sandy Soils Under Semi-Arid Mediterranean Climate

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Abstract: This research has for object to study the influence of clay addition, i.e., Maghnian bentonite, like deposit clay, in the physical properties of sandy materials from Mostaganem plateau (North-West Algeria) submitted to salinity and sodicity. The first result was to show that the clay content changes drastically the physical properties of clay-sand mixtures. Important differences were observed as a function of the sand particle size distribution. At given clay content, the saturated Hydraulic Conductivity (HCs) was lower when the sand size was small and spread. For the coarse sand the salinity was maintained, even for high clay contents, a significant hydraulic conductivity. One of the main characteristics of Maghnia clay is the presence of calcium carbonates in the natural material. In comparison to that of Mostaganem clay of other deposit, it appears less sensitive to sodicity. An important aspect is the initial state of the clay when used in addition to sands, i.e., disturbance, conditions of preparation of sand clay mixtures and presence of associated components such as carbonates. Maghnia clay appeared to be adapted to the improvement of sandy soils, not because its mineralogical characteristics, but for its natural cationic form and obviously the presence of calcite in it.

Key words: Sandy soils, bentonite, aridity, salinity, sodicity, electrical conductivity, saturated hydraulic conductivity

INTRODUCTION

In arid and semi arid zones, sandy soils often presents in dominance, are reputed by their physical and chemical deficiencies. The recourse to clayey amendment for correct their original deficiencies was envisaged to improve particularly their available water retention (Bousnina and Mhiri, 1997; Benkhelifa, 1997; Halilat and Tessier, 2006). Essentially, the work contributions concern the physical and hydrical behavior of the sand-clay mixtures and consider very littlie the effect of the salinity and the sodicity (Halilat, 1998; Halilat and Tessier, 2000).

However the clay addition always poses problem because of its stability within a sandy material. Indeed, a partial colmatage of the porosity can lead to some important decrease of the hydraulic conductivity witch is be a problem for root penetration. This is especially right that in arid and semi-arid zones, soils are submitted to strong hydric deficits and therefore to strong variations of water potential. It can result a mobilization of clay particles during the soil brutal humectation. In addition, it is posed the problem of the local accumulation of salts in the rhizospher that for all more reason the plant practically doesn't absorb salts and has tendency to make their accumulation at roots proximity (Bernstein, 1975). It can lead to some problems of water nutrition of culture and consequently a structural instability of the material at the humectation time (Bauder and Brock, 2001; Chaudhari and Somawanshi, 2004).

In this context, it is important to really understand the scientific bases of the properties of the clays in order to optimize the mixture properties. In the sandy soils, one of the determining parameters is the particle size distribution of the sand himself. The form of grains influences the cohesion and the deformation of the sands (Lesturgez, 2005). In the case of the Algerians soils, sands generally underwent the important aeolian transportation because of their faraway source close to the Sahara. In this context, the form is associated to the deposit mode and sands are mainly of rounded shape. This shape is bound to the many shocks that they underwent at the time of their transportation. The sand that we studied is representative of the aeolian sands of the plateau of Mostaganem (Larid, 1993).

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If it is important to compare the effect of the texture (mode and size distribution) of the sands on the properties of sands clay mixtures, we must also consider the properties of the clay herself. Indeed, besides its specific role in the mixtures, this material is last used traditionally at the natural state by the local agriculturists in arid regions of Algeria (Dubost, 1992), notably in the oasis under palm for market culture (Rouvillois-Brigol, 1973; Bisson and Callot, 1990; Nasr, 2004) or for the fresh fruit tree plantations. In this last case, the burying of clay in depth is then the indispensable condition to produce citrus fruits in the gardens and the small agricultural exploitations. The clay use then as physical gate to the water of infiltration and play the role of reservoir where concentrates the root system.

Different deposits are available in the countries of Maghreb. As showing by many researchers in Algeria, Morocco and Tunisia, one of the specificities of the soils of these regions is that they are developed on clayey sedimentary materials and greatly carbonated. These materials contain quantities of clay of the order of 30 to 50% but their content in swelling minerals like smectites is weak (Ben Rhaiem *et al*., 1987; Laribi *et al*., 2005). Otherwise, considering the geology of Algeria, some important deposits of bentonite formed themselves by change of the volcanic rocks at the level of the seismic zone that crossing the whole Maghreb (Gaucher, 1974; Belaroui *et al*., 2004). We chose here to study specifically one clay, whose origin is descended of one of these volcanic deposits named *Maghnia*, that has been characterized little until then and that will be able to be compared to other clays coming from similar deposit (Sadran *et al*., 1955; Khalaf *et al*., 1997; Belaroui *et al*., 2004).

It is important to take account, in this survey, the abiotic constraints of salinity and sodicity that characterizes the arid and semi arid regions. These constraints are bound to a soluble salt accumulation in the rhizospher due to the rare rain fall and to the elevated temperatures that characterize these regions (Halitim, 1984; Hillel, 2005). The phenomenon of secondary salinisation of the irrigated perimeters constitutes a particularly serious threat. In Algeria, 10 to 15% of the irrigated areas are reached by the secondary salinisation phenomenon (Cheverry and Robert, 1998; Bessaoud, 2006).

This study has for object to sum up the properties of sand-clay mixtures submitted to the abiotic constraints of salinity and sodicity and to compare the results gotten with others bibliographical data. It is not about in this survey, to use the bentonite of Maghnia systematically for the sandy soil improvement in arid, semi arid and coastal middles, but to optimize its use as adjusting it to best measures to use it according to the particle size of the sand and the nature of the irrigation water (concentration in soluble salts and sodium absorption ratio (SAR)).

MATERIALS AND METHODS

This study was conducted in the laboratory of soils sciences of the Department of Agronomy at University of Mostaganem (North-West of Algeria), during the second semester of 2005 year.

Experimental device: We create a range of materials from 2 sands to which we adds different proportions of bentonite. With the sand 1, we make a set of mixtures 0, 5, 10 and 15% of bentonite; with the sand 2, another set of mixtures 0, 10, 50 and 100% of bentonite. We irrigate these materials with a range of percolated solutions of salinity and sodicity (SAR) variable to measuring the HCs. For the range 1, the values of the SAR are 0, 10, 20 and 30; for the range 2, they are 0, 15, 30 and 45. The values of the salinity of the percolated solutions are for the two ranges of 10, 100 and 1000 $cmol^{+}\ L^{-1}$. The distilled water with null salinity and sodicity is taken for the witness solution. The measures of saturated hydraulic conductivity are repeated three times according to the device of random complete blocks. We did a statistical two way analysis of variance to study the relative effects of the salinity and the sodicity on the HCs (Dagnelie, 2006).

In the first range of measure, we look for the response of the substrata to a medium sodicity ranged as her appears in arid regions and semi arid of Algeria (Daoud and Halitim, 1994). The choice of the clay doses follows the works of the sandy soils improvement of sandy soils by the bentonite in which the optimal dose of 10% is surrounded by these of 5 and 15% (Benkhelifa, 1997). In order to permit an exhaustive survey of the effects of the salinity, it is necessary to take more important concentrations: 10, 100 and 1000 $cmol^{+}\ L^{-1}$ (Halilat, 1998).

In the second set of measures, the range of sodicity is more important (SAR 45), what permits to express extremely stern conditions of aridity of the arid and semi arid regions of Algeria (Daoud and Halitim, 1994). In this last case the raised clay contents permit to determine the behavior clean to the clay.

Materials

Characteristics and preparation: We have selected two sandy samples in two sites located in border seaside (near the Mostaganem town), (respectively Sablettes: sand 1 and Salamandre: sand 2) that we have washed with water, after with HCl and in the end with the bleach in order to assure their disinfection and to limiting their proliferation by the micro-organisms. Sands are finally rinsed many times with distilled water. The obtained substrates are braised at 105EC during 24 h. Its size of particles is determinate with Laser Coulter LS230, range between 0.04 to 2000 μm divided on 116 fractions, with a solid laser of gallium arsenide of 50 mW and λ = 750 nm (Dur *et al*., 2004). The particle size distribution of sand 1 is including between 0.15 and 0.71 mm, with a diameter ϕ_{70} equal to 0.28 mm, then of sand 2 fluctuates between 0.16 and 0.85, with a ϕ_{70} equal to 0.40 mm. This last sand is so relatively to coarser than the sand 1. We have estimate the sphericity and shapely rating too for 100 grains for each sand according to the classic method of characterization (Cailleux and Tricart, 1963). According to the chart of estimation for this two parameters (Chretien, 1971), the sphericity index records values higher than 50% at 0.7 for the two sands, what means that the shape has a tendency round relatively more connoted for the second sand by report to the first one. In the other hand, the shapely rating records, equally for the two populations of sand, the values of cumulated percentage is less than 20% at 0.3 and higher than 60% at 0.7.

It shows, that the particles are of general shape rounded for the two sands, especially for the second, coarsest. This shape assigns them an aeolian origin therefore. It is known indeed in the literature that this type of material evolves essentially under rounded shape, due to a long way of the sand particles under the effect of violent wind shocks (Cailleux and Tricart, 1963; Chretien, 1986).

The bentonite comes of a deposit located in the right bank of the Tafna on the South-East of Maghnia city (North-West of Algeria) with some characteristics shown in Table 1.

After drying in the dryroom at 105°C during 24 h, the mixtures are done by hand then for the two sets at dry state and decanted in the columns of the device of measure of HCs (Kheyrabi and Monnier, 1968; Fiès, 1971) that consist to introducing the sand-clay mixture by successive thin layers in order to assure the homogeneity of the whole.

The saline solution is composed by two salts, the sodium chloride (NaCl) and calcium le chloride ($CaCl_2$). Table 2 shows relative contents of the two salts for obtaining the values ranges of SAR and saline concentrations used for the two sets of measures. This values are obtained using the following equations: SAR = $[Na^+]/([Ca^{++}]+[Mg^{++}]/2)^{0.5}$ and $[Na^+]+[Ca^{++}]$ = 20[C], with [X]: concentration of element X in meq L^{-1} in the solution and [C]: concentration of saline solution in $cmol^+ L^{-1}$.

Table 1: Physical and chemical characteristics of bentonite (Bendella, 1994)

Constituents	Content
$CaCO_3$ (%)	15.50
Humidity at retention capacity (%)	79.50
Organic carbon (%)	0.15
Organic matter (%)	0.26
pH_{water}	8.00
EC_{spe*} (dS m^{-1})	1.40
CEC (cmol$^+$ kg^{-1})	64.00

*spe: saturated paste extract

Table 2: Chemical compositions of NaCl and $CaCl_2$ solution (g L^{-1})

Concentration (cmol$^+$ L^{-1})	SAR	NaCl (g L^{-1})	$CaCl_2$ (g L^{-1})	SAR	NaCl (g L^{-1})	$CaCl_2$ (g L^{-1})
10	0	0.00	11.08	10	4.61	6.75
100		0.00	110.80		17.26	94.61
1000		0.00	1108.00		57.60	1053.97
10	15	6.14	5.32	20	7.30	4.23
100		24.89	87.45		31.91	80.87
1000		85.32	1027.96		112.35	1002.60
10	30	8.86	2.77	45	10.10	1.60
100		44.29	69.25		59.30	55.17
1000		164.38	953.80		237.53	885.17

Methods: The measure devise of HCs (Aubert, 1978), is composed by four gradual columns connected to a horizontal tube linked by a faucet to a other balloon of Woolff itself alimented from another small balloon of Woolff with another faucet. The superior Woolff balloon aliments the one situated to a lower level whose role is to assure a constant level on the samples columns. This last nourishes the columns by the horizontal tube. After establishing balance between the solution and the sample, the introverted solution volumes are measured at the end of 1 h of percolation.

The saturated hydraulic conductivity HCs (cm h^{-1}) is obtained with the following relation (Aubert, 1978):

$$HCs = C \times V/H \times S$$

Where:

C = Height (cm) of the sample column,
H = Height (cm) of the water load,
V = Volume (mL) collected water during 1 h,
S = Interior section (cm^2) of the column.

Before undertaking the measure of HCs, we did percolating the saline solution through the sample until the Electrical Conductivity (EC) of collected leaching solution equalizes the EC of saline solution. The balance times changed according to the bentonite dose and relative contents of salinity and sodicity in the middle. The EC is measured with a conduct meter in saturated paste extract (Allison *et al*., 1954; Rhoades *et al*., 1989).

RESULTS AND DISCUSSION

First set: sand 1: The EC of saturated paste extract for substrate increases under growth effect of saline concentration and SAR (Fig. 1). This parameter increases

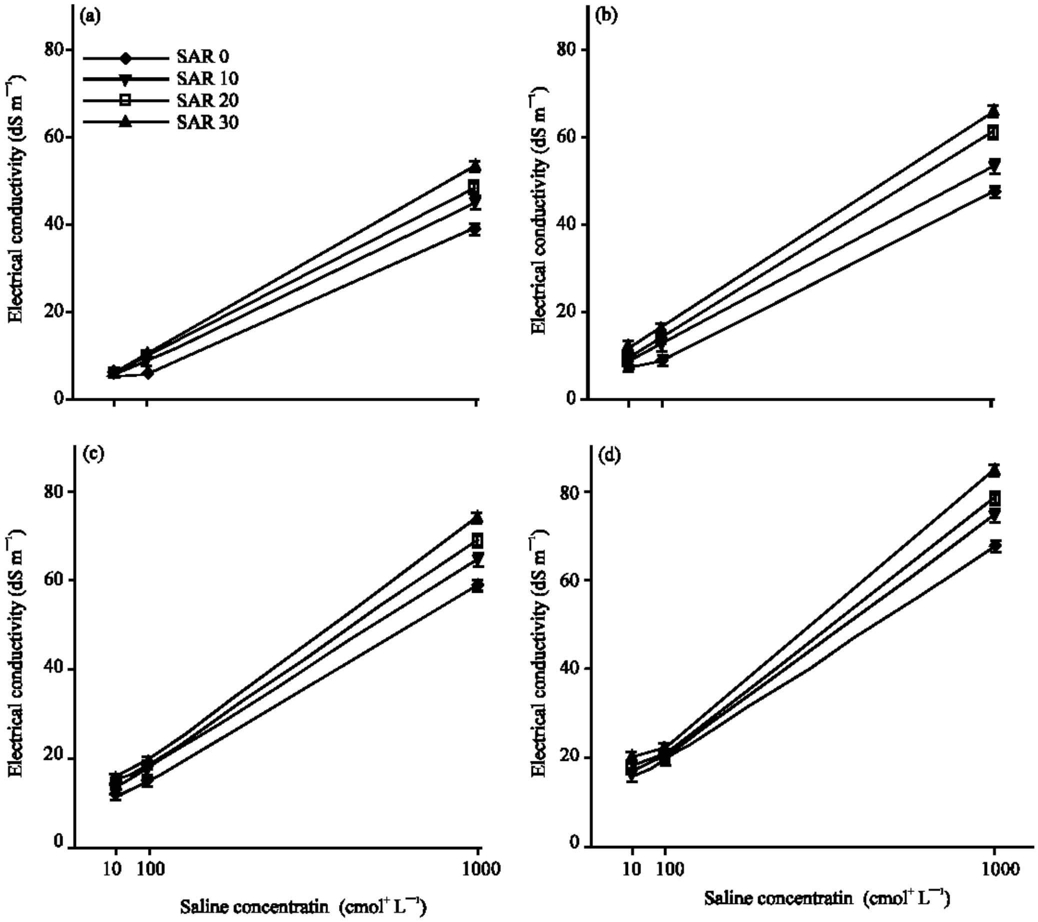

Fig. 1: Effects of salinity (cmol$^+$ L^{-1}) on the EC according to the dose of bentonite and the sodicity (SAR, 0 to 30) for the mixture clay-sand 1, (a) 10% of bentonite, (b) 5% of bentonite, (c) 10% of bentonite and (d) 15% of bentonite

slightly with the growth of the clay dose and becomes important for the concentration of 1000 in relation to 10 and 100 cmol$^+$ L^{-1}.

The HCs decreases under growth of the bentonite dose and SAR (Fig. 2). The saline concentration effect for the dose 10% of bentonite becomes particularly apparent in relation to the witness. The differences in the values of the HCs between the SAR 0 and 30 are especially raised than the saline concentration is weaker. The HCs constitutes one of the most important parameters to debate effects of the salinity and sodicity on soils (McIntyre and Loveday, 1979; Chaudhari, 2001; Dikinya *et al*., 2006).

Second set: sand 2: The results of HCs to mixtures (Fig. 3), show that it is in the first place function of the clay content. This parameter passes 200 to 0.1 cm h^{-1} between the sand to the pure clay what is coherent with the data of the literature. This parameter (HCs) varies also according to the saline concentration. Globally, the HCs

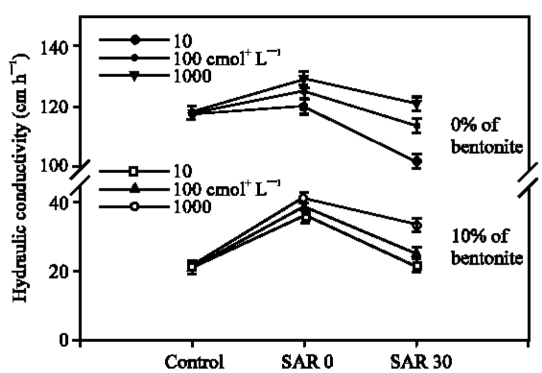

Fig. 2: HCs (cm h^{-1}) of mixture bentonite-sand 1, according to the salinity (cmol$^+$ L^{-1}) and sodicity (SAR, 0 and 30)

increases with the saline concentration in the domain of the weak SAR, that is to say of 0 to 15. It agrees to note the existence of a significant variation of HCs also, even

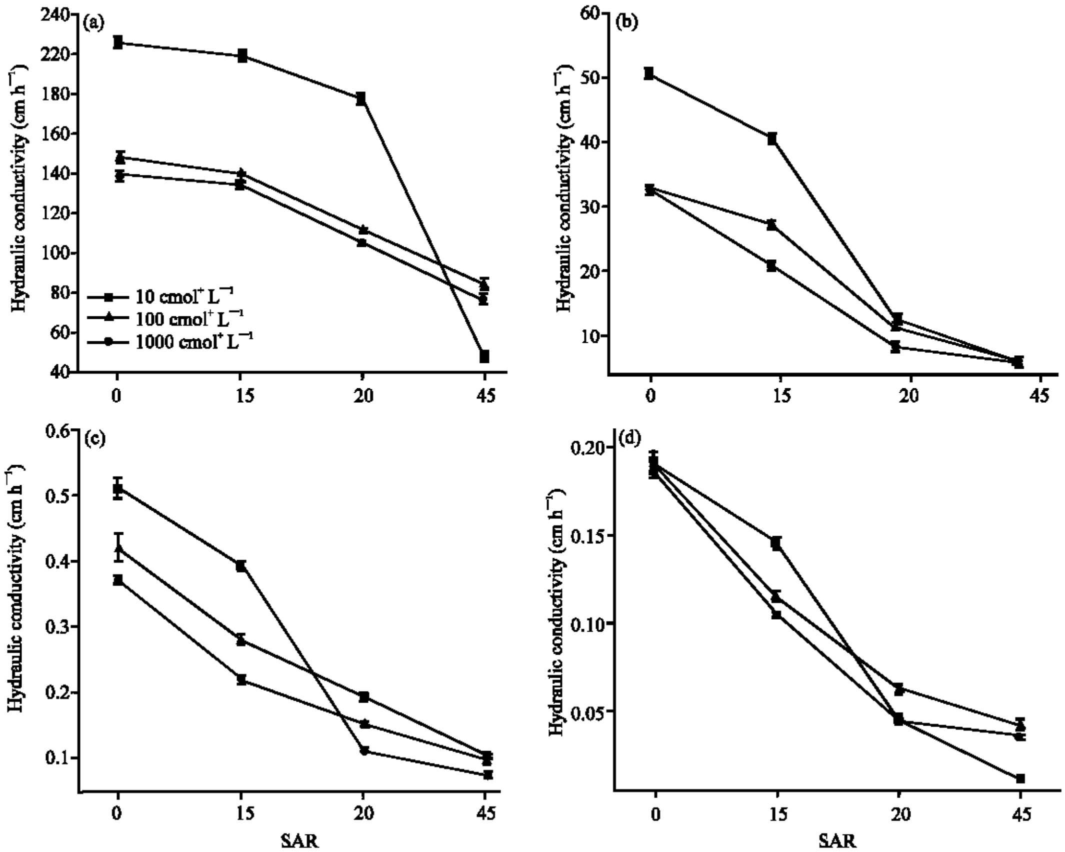

Fig. 3: Effects of salinity (cmol$^+$ L^{-1}) on the HCs (cm h^{-1}) of mixture bentonite-sand 2, according to the dose of clay and sodicity (SAR, 0 à 45), (a) Sand, (b) Sand+10% of bentonite, (c) Sand+50% of bentonite and (d) 100% of bentonite

for the pure sand, between 10 and 100 cmol$^+$ L^{-1} on the one hand and for 1000 cmol$^+$ L^{-1} on the other hand.

The influence of the SAR permits to decrease strongly the HCs to the weak saline concentrations and for the high contents of clay. In this case, the HCs can reach extremely weak values (0.1 cm h^{-1}).

This survey raises several questions notably the importance of the texture of the sands in the addition of clay to one soil, the role of the clay according to its nature and the one of the constituents associated and finally the respective roles of the salinity and the sodicity in the clay-sand mixtures.

Effect of the sands textures on the behavior of the mixtures: In this work, the mixtures of sand-clay are studied while considering two sands with different particles size distributions. The results show that the HCs (Fig. 2, 3) is superior, at identical clay content, for the sand 2, coarsest (D_{70} = 0,40 mm) in relation to the sable1, fine (D_{70} = 0.28 mm). Otherwise, we observed previously that the content of clay is the main parameter controlling the HCs (Fig. 3). However it is interesting to

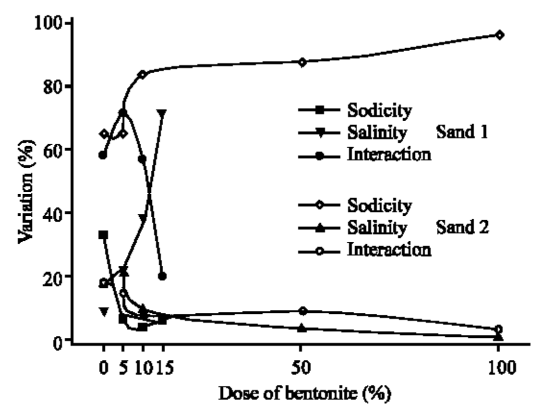

Fig. 4: Influence parts of salinity and sodicity on the global variations of the HCs for the two ranges of clay content

analyze for the two sands, the effects of the variables of sodicity and salinity, very important in the arid region soils in relation to the global variations of the HCs.

The results by the statistical two-way analysis of variance (Fig. 4) indicate that the influence part of sodicity in the global variations of the hydraulic conductivity is not the same in the two mixtures clay-sand. For the more fine sand (sand 1), we observe an increase of sodicity effect in the hydraulic conductivity for 5% of bentonite, then a decrease for 10% and at last a fall for 15% of clay. On the other hand, the specific effect part of salinity in the hydraulic conductivity increases continuously next to the augmentation of clay content. To regarding, what we know about the salts and exchangeable sodium role, it means that the salinity controls, via the swelling limitation of clay in saline middle, one good part of intergrains porosity, same at high clay content (Radi, 1991).

In the case of coarse sand (sand 2), the sodicity effect increases progressively with the clay content at the contrary of the decreasing salinity effect.

In this way for 100% of bentonite, the sodicity explains nearly 97% of clay behavior, however the salinity effect is only near 0.35%. The interaction effect goes to the same salinity variations but in more high proportions. It means that the sodicity is the principal factor of porosity colmatage since it allows to the clay to express itself swelling in the porous space delimited by the sand particles. That's confirmed by other works, where the saline solution can make multiplication with a factor of 3, the clay swelling at a water potential near the saturation state (Tessier, 1984).

To analyze the evolution of the HCs it is not only important to refer to the modal size of the grains, but also to the particle size distribution that really controls the porous space. To this effect, Molle (2003) show that more the grains are of small size and spread size distribution, more the HCs is weak. The display of the size distribution of a sand is expressed by the coefficient of uniformity (CU) equivalent to the report of two diameters of the particles of a sandy material while taking the sizes of grains corresponding respectively to 60 and 10% of the particles of the material: $CU = d_{60}/d_{10}$, (d_{60} is a value of the diameter of which 60% of the material = d_{60} mm and d_{10} is a value of the diameter of which 10% of the material = d_{10} mm). If the CU<2, the size distribution is uniform and so CU>2 it is dispersed.

From the measures with the laser granulometer the CU coefficient can be defined: for the sand 1 this coefficient is of 1.47, whereas it is of 1.32 for the sand 2. It means that the two sands have a uniform size distribution, although it is for the sable 1, the fine, relatively more important than for the sand 2, the coarse. It is why, the values of the HCs gotten for the first sand are even weaker than those waited considering its modal size. It confirms a hydraulic behavior difference between the two sets of measure essentially linked to the textural ranges of the two sands. In all survey on the improvement of sandy soils properties is thus, therefore important to know its modal size, but also to have some information on the uniformity of the size distribution of sands.

Otherwise it is interesting to compare our results with those of Halilat and Tessier (2000, 2006). With a CU = 1.5, the sand used by this author presents a spread size distribution that comes closer of the sand 1 of our survey. Let's note that in this case, the sand is slightly different to a textural point of view but also on a morphological level since its facies are at a time oval and angular, whereas it is rounded in our case. To this topic, Chretien (1986), working on the porosity of mixtures of clay and populations of sand with different size distributions and shapes, concludes that the variations of the porosity are not owed to the nature of the clay, nor to the mode of samples preparation, but essentially to the differences between the textural ranges of the skeleton.

Specificity of the bentonite of maghnia: It is to notice that, in our survey, the clay doses implicated to reducing the HCs strongly are a lot weaker than in the clayey soils. So, Chretien (1986) show that it is necessary to reach a clay content of 30% to assure a replenishment of the inter grains porosity of the sands. It becomes therefore difficult to compare clay of deposit directly like the bentonite of Maghnia and clay of soil, how much it is a smectite. For the bentonite of Maghnia, the swelling properties are so strong that a dose of 12% is sufficient to modify the properties completely. It is in agreement with the results gotten by Halilat and Tessier (2000). Otherwise, Tessier (1984) showed that the behavior of the clays of deposit as the montmorillonite and those of soils as Béthonvilliers are of very different scale. The comparison cannot make itself directly enters clays of soils of sedimentary origin and the clays of deposit descended of the volcanic origin alteration.

Characteristics of the deposit smectite compared to those of soils can probably be joined to the value of the superficial electric charge and to its localization (Ben Rhaiem *et al*., 1987). All works of the literature demonstrate that the deposit clays descended of the volcanic origin alteration are very sensitive to the sodicity and that it drives to a dispersion of the clays. One of the possible ways to use of this clay type, in order to maintain sufficient HCs to the limitation of the colmatage risks linked to the effects of salinity and sodicity of substrate, is to optimize the choice of the dose to bring. This optimization must be reflexive according to the size and the distribution uniformity of the sand as well as the salinity of the water irrigation and its degree of sodic aggressiveness (Mamedov *et al*., 2001). The quality of the waters irrigation is not of the best in the arid and semi-arid zones of Algeria, for example in the region of Ouargla (South-East of Algeria), where the SAR fluctuates between 2,3 to 32 and drags a salinisation by irrigation of 3 to 5 times the one of water irrigation in the superficial horizon (Daoud and Halitim, 1994). In this case, the clay dose to adopt must be as the sodicity doesn't drag a significant decrease of HCs. It can explain itself like a limited swelling of the clay in the matrix of mixture so that the continuity of the pores between the grains of sands is not colmated by the clayey colloids. So to strong saline concentration (1000 cmol$^+$ L^{-1}), the force of cohesion between the grains of sands are increased strongly in presence of salts, so that the downfall of the grains assembly during the tests of HCs is limited more that to the weakest concentrations in salts. This property is verified for the values of the active SAR until 30.

The clays have the swelling properties that depend at a time on their purity, their mineralogical type, but also the presence of associated substances who can orient their properties, for example the presence of salts or carbonates (Caillere *et al.*, 1982; Keren and Ber-Hur, 2003; Sally and David, 2004). Beside the fact that the mode of preparation of clay amendment is important, the fact to modifying a sample in water increases considerably its hydratation properties. It is the reason for which in our survey the clay has been added to the dry state, therefore no remanied in water, in order to limit the colmatage of the porosity. Besides it is a protocol as used traditionally in Algeria to improve the sandy soil properties.

CONCLUSIONS

In this study, we tried to show the interest of the bentonite of Maghnia as mineral amendment for essentially sandy soils submitted to abiotic constraints of salinity and sodicity. It constitutes an interesting setting for the field survey of amendments to basis of clay.

This clay, apart from the calcite that is intimately associated, is essentially saturated by calcium that limits its swelling. It is necessary to reach values of the water SAR of irrigation of 45 so that the HC in saturated state of the mixtures approaches the threshold of impermeability. It means that the proportion of sodium in the soil solution must be raised so that there is a significant exchange with sodium. Our results show that the salinity has an effect contrary to the one of the sodicity on the HCs, since it has the tendency to reduce the swelling properties of the clay and therefore to limit the volume of the clay within the sand matrix. It results that the porosity of assembly of the grains of sands is not completely full by the clay assuring a certain HCs. It is to note that the salinity threshold of 1000 cmol$^+$ L^{-1} and sodicity of 45 used in this survey, represent some extremely stern conditions of aridity. These thresholds demonstrate that the use of this bentonite is much appropriated for the physical and hydric sandy soil improvement and so attenuation of deterioration effects of the structure by abiotic constraints of salinity and sodicity in arid and semi-arid area. For this clay, the effects of the sodicity and the salinity are a lot more tamponed to the one of Mostaganem. Otherwise, although in the case of fine sand and under an important saline-sodic condition of middle, the conduct of the irrigation should be do with a particular attention especially. The bentonite use under brut form extensively reserved to local practices, notably in the setting of market or domestic productions, can also apply to the plantation of trees by burying to the basis of the root system. This practice can nearly constitute an alternative for arboriculture practically absent in arid and semi-arid zones and same littoral of Algeria.

This survey, do not recommend to using systematically the bentonite of Maghnia for the sandy soil improvement in arid, semi arid and littoral regions, but it is in purpose to optimize its use by adjusting to the best the dose brought in according to the size distribution of sand and nature of the water irrigation too (concentration in soluble salts and SAR).

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