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Impact of Salinity on the Physical Soil Properties in the Groundnut Basin of Senegal: Case Study of Ndiaffate

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Summary

This study was conducted during the rainy season (september) to evaluate the impact of salinity on the soil physical properties. The area of study is composed of agricultural (ZC) and salt production (SA) area, none vegetalized (TV) and little vegetalized (TA) spots.

Our methodological approach is based on a sampling of soils in different depth (0-20; 20-40, and 40-60 cm), the measurement of their physical properties (bulk density, infiltration test) and chemical caracteristics (pH, EC, exchangeable bases, etc.).

Our results show that the measured values of electric conductivity (14 $\mu S.cm^{-1}$ in ZC and 3290 $\mu S.cm^{-1}$ in SA) indicate a gradient of salinity from the agricultural activities zone (ZC) towards the salt production zone (SA). The values of bulk density and infiltration, vary according to a gradient of salinity which goes decreasing from the none vegetalized spots (TV, (> 2.40 $kg.m^{-3}$; 0 $mm.h^{-1}$) to the little vegetalized spots (TA, (2.4 $kg.m^{-3}$; 0.2 $mm.h^{-1}$), the salt production area (SA, (2.32 $kg.m^{-3}$; 2.4 $mm.h^{-1}$) and finally to the zone of agricultural activities (ZC, (2.12 $kg.m^{-3}$; 14 $mm.h^{-1}$).

This result establishes a relation between the gradient of salinity and the modification of the studied soil physical parameters. The practice of salt production involves an increase in the salinity of the soils.

Keywords: salinisation, gradient of salinity, bulk density, infiltration, groundnut basin

1. Introduction

In Senegal, the agricultural sector is marked, by a reduction of the productivity of the soil affected by the salinisation. This phenomenon results from a process of general degradation which goes back to the Seventies and which has affected $\frac{2}{3}$ of the arable lands of Senegal (BM, 2008), 2.5 million hectares and approximately 34% of the surface of the country (CSE, 2011). This salinisation results in an enrichment out of soluble salts which reduces the soil textural stability, its rate of infiltration and water storage capacity.

The study carried out on the salinisation shows that 80% of the salinized soils belong to natural origin and 20% have an anthropic origin (PAPIL, 2013). In the agro-ecological zone of the groundnut basin which covers Kaolack and Fatick regions, the salted soils extend on 201 237 ha, which represents 17.49% of the soil in this area.

The area of Ndiaffate which covers 209 km^2, in the region of Kaolack, is one of the most affected by the problem of salinity. The salinisation results in general from the presence of the sea but more especially the practice from salt production.

This study aims to understand the major changes caused by the salinisation on the soil of Ndiaffate. It will be a question of analyzing the physical properties (granulometry, apparent density, etc) and the chemical properties (electric conductivity, pH, bases exchangeable, etc) of the soil. This study will be useful to understand how the salinity affects the soil physical properties

2. Material and Methods

2.1 Material

The studied material is constituted by soils which result from tertiary sedimentary formations of the Continental terminal (CT). They are subjected to degradations from natural phenomena such as hydrous erosion, marine intrusions or human activities (Sanokho, 2007). These degradations involve in all the cases a lower temporary or permanent of the productivity. The study related to soils of the agricultural area (ZC), the salt production area (SA), the none vegetalized spots (TV) and the little vegetalized spots (TA).

Our experimental site extends on approximately 4 km2. It is subjected to the phenomena of marling with a broad opening on the sea. A broad formerly arable soil, is abandoned today due to salinity (Manga, 2012) (Figure **1**). The relief is a relatively flat, and the vegetation is made up primarily of grass, shrubs, trees, classified forests (Kousmar, Koutal, Keur Matar, and Védor) and protected forests. The climate is characterized by eight month of dry season, from October to May, and three to four months of rainy season, from June to September. The annual pluviometric averages vary between 800 and 900 mm (GERAD, 2012).

2.2 Methods

The points of surveys were identified and chosen based on the soil occupation (Figure 2) which made it possible to distinguish four zones: agricultural activities (ZC) ; salt production (SA) ; little vegetalized spots (TA), and none vegetalized spots (TV). Respectively, they cover a surface of 122.3 ha, 128.6 ha, 45.9 ha and 84.4 ha (Manga, 2012).

The geographical location of the points of surveys was raised using a GPS. The sampling and the infiltration tests were carried out on a surface of 1 m^2 to attenuate the risks of error which can be induced by the variability of the soil properties.

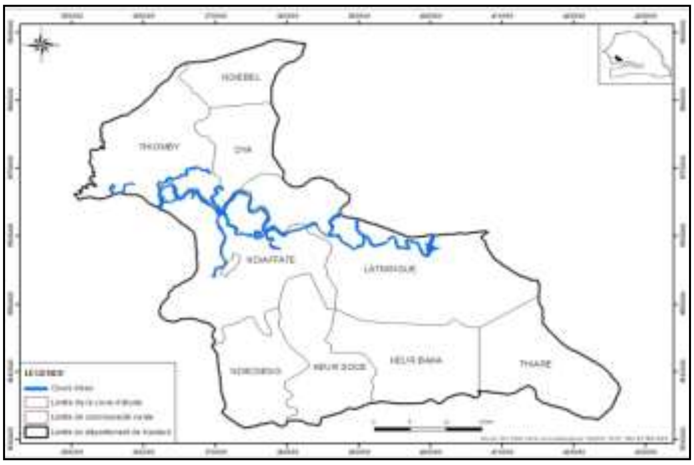


Figure 1. Localization of the site of Ndiaffate.

For each type of occupation, three samples of soil were taken for the determination of physical (bulk density, infiltration tests, etc.) and chemical (electric conductivity, pH, bases exchangeable, etc.) parameters to the respective depths of 0-20, 20-40 and 40-60 cm. Thus twelve samples by depth were identified, conditioned and sent to the laboratory for analysis.

The bulk density was measured by the method of the grooved roll of $14{,}025.10^{-5}$ m^3. Volume was estimated in situ and the weight at the laboratory after drying to 105 ℃. The bulk density was given from these two variables according to the relation:

$$da = \frac{P}{V} \text{ in Kg.m}^{-3}$$ (Yoro and Godo, 1989-1990) ;

where *P* is the dry weight of the sample and *V* the volume of the taken and dried sample.

The rates of infiltration were carried out in situ by the method of the double ring which is based to the measure of the water flow which infiltrates on a delimited under ground surface of to which we apply a constant hydraulic head (Figure **3**).

The granulometric analysis was made on the fine ground : each sample was crushed and filtered using a sieve of 2 mm. The grains were classified according to their size and the frequencies of the grains of a given class were evaluated by weighing the fractions retained on the successive sieves.

The mesure of the pH was made on the suspension of the soil (ratio soil/water, 2.5) using a pH-meter.

Figure 2. Occupation of the soil of the site of Ndiaffate (modified Manga, 2012)

The electric conductivity (EC) was measured on a suspension of soil prepared in distilled water (ratio soil/water at 1/10). It is expressed $S.cm^{-1}$ or in $\mu S.cm^{-1}$.

The moisture of the soil was obtained after drying with the drying oven during 72h the wet samples contained in jars out of glass.

Figure 3. Device infiltration test measurement

3. Results

3.1 Soils Physical Parameters

The granulometric analysis (Figure 4) indicates that the soil of the none vegetalized spots (TV) are silty-clay from 0 to 40 cm and clay in-deeper parts of the pits (40-60 cm). The soils of little vegetalized spots (TA) are silty-clay in the upper parts (0-20 and 20-40 cm) and clay from 40 to 60cm). The soils of the salt production area (SA) are loamy-sand from 0 to 60 cm and finally, the soils of the ZC are loamy sand with sandy-loam on all the pit (0-60cm).

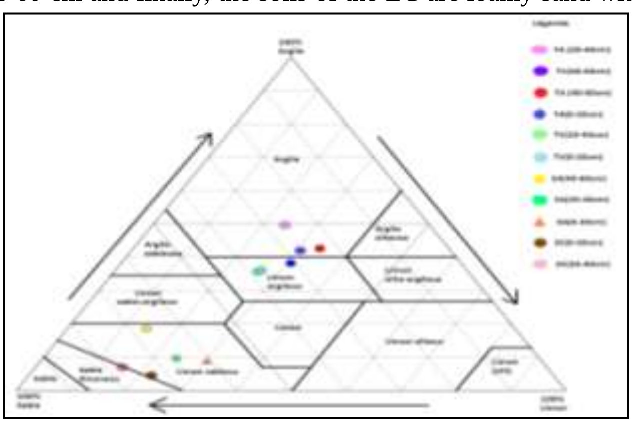
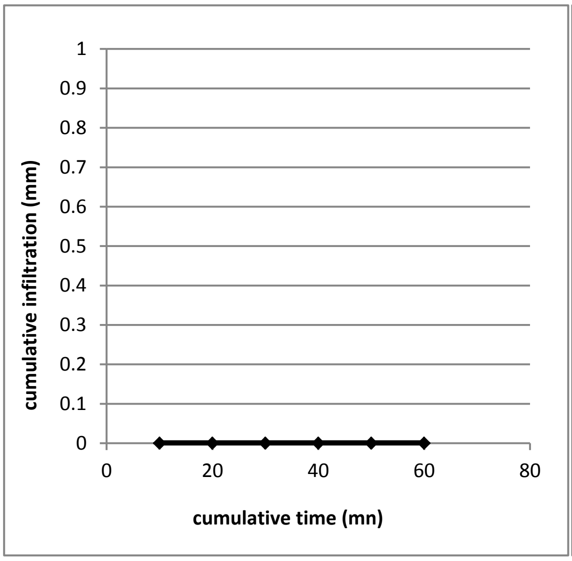


Figure 4. Textural diagram of the soil according to the types of occupation (SA, TV, TA, ZC)

The texture of a ground has a direct effect on its fixing power of nutritive elements for the plants, its holding capacity in water its capacity of drainage.

The in situ rate of infiltration expresses the vertical flow of water in permanent mode. It makes it possible to envisage the water management of the soil in the case of the market-gardening activities for example.

In TV, no infiltration was recorded after one hour (00 $mm.h^{-1}$, Figure 9). In TA, SA and ZC, water infiltrates quickly at the beginning of the operation; this stage corresponds to the initial rate of infiltration (Figures 10, 11 and 12). As water fills the soil porosity, the rate of infiltration decreases and reaches a relatively constant value for each soil type : 0.2 $mm.h^{-1}$ in TA, 2.4 $mm.h^{-1}$ in SA and 14 $mm.h^{-1}$ in ZC. This stage corresponds to the rate of infiltration in permanent mode which varies according to the soil type. It is reached at the end of 114 mn in ZC, 115 mn in SA and 45 mn in TA.



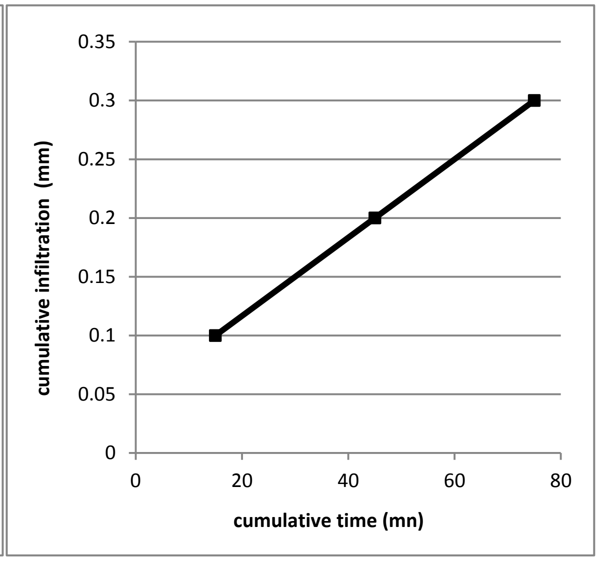
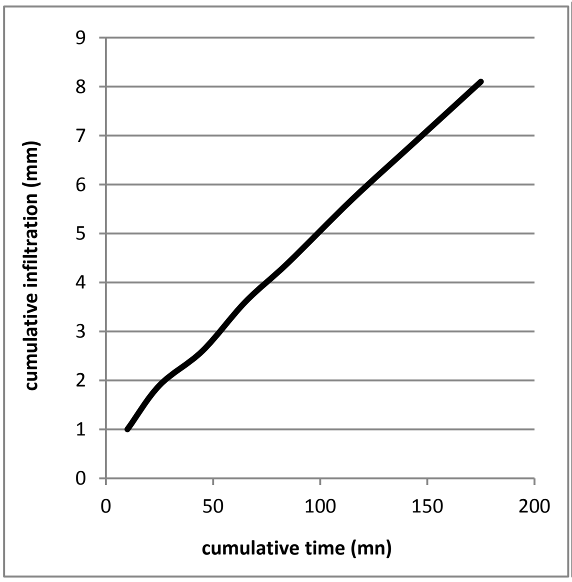


Figure 9. Variation of the rate of infiltration, TV Figure 10. Variation of the rate of infiltration, A



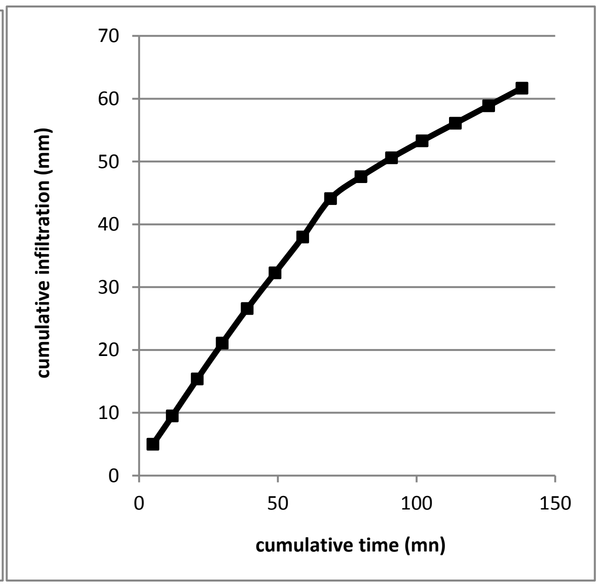


Figure 11. Variation of the rate of infiltration, SA Figure 12. Variation of the rate of infiltration, ZC

The bulk density (*da)* makes it possible to evaluate the levels of compaction and compressing of a soil which involves a reduction in its porosity. Compressing affects all textural porosity, but it is more intense near the surface of the soil where the pressures are applied. This textural porosity plays a central role in the operation of the soil-plant system, because it ensures the transfers of water and air, and the storage of water usable by the plants.The figure 13 below, indicate that the bulk density varies according to the type of occupation and salinity.

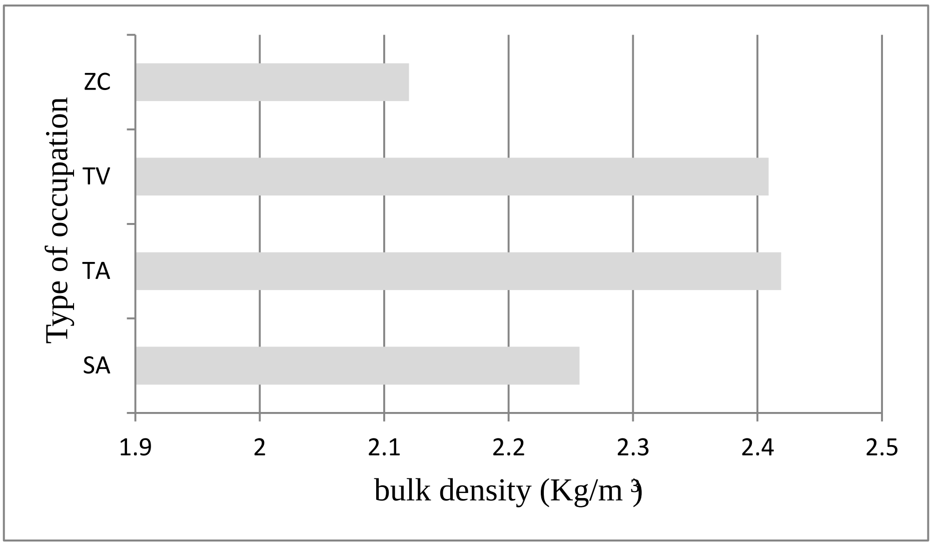


Figure 13. Variation of the bulk density according to the type of occupation.

In the soils of TV, the bulk density is high (da > 2.40 $kg.m^{-3}$). In the other types of occupation the values of *da* are 2.4 $kg.m^{-3}$ (TA) ; 2.32 $kg.m^{-3}$ (SA) 2.12 $kg.m^{-3}$ (ZC).

It is noticed that the bulk density increases in the direction of a gradient of salinity from the ZC towards TV.

3.2 Soils Chemical Parameters

The results of electric conductivity (EC), show that : the soil of ZC are unsalted (CE < 250 $\mu S.cm^{-1}$); the soils of the little vegetalized spots (TA) are salted to very salted (EC, 500 - 2000 $\mu S.cm^{-1}$) ; the soils of the none vegetalized spots (TV) are very salted to extremely salted (500 to more than 2000 $\mu S.cm^{-1}$) and the soils of the zone of salt production (SA) are extremely saline (CE > 2000 $\mu S.cm^{-1}$) (Durand, 1983).

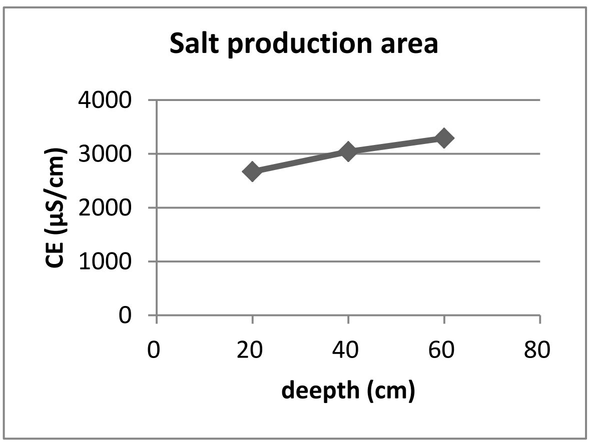


Figure 5. Variation of the EC ($\mu S.cm^{-1}$), SA

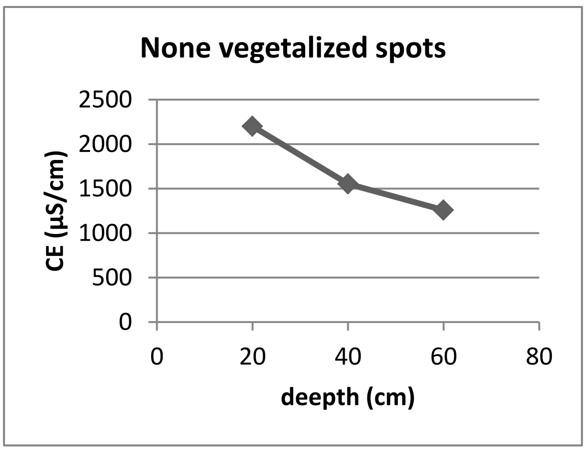


Figure 6. Variation of the EC ($\mu S.cm^{-1}$),TV

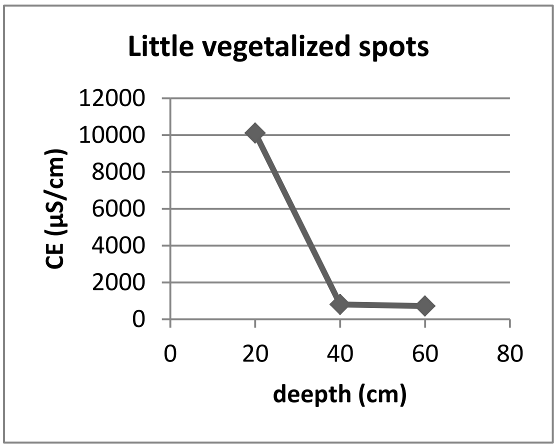


Figure 7. Variation of the EC (µS.cm^{-1}), TA

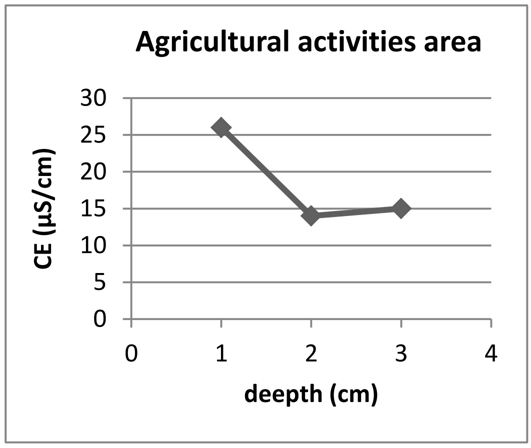


Figure 8. Variation of the EC (µS.cm^{-1}), ZC

The electric conductivity shows a gradient of salinity which grows from zones of agricultural activities : ZC (14 µS.cm^{-1}) towards the zones of salt production : SA (3290 µS.cm^{-1}) while passing respectively by the zones of little vegetalized spots : TA (1014 µS.cm^{-1}), and none vegetalized spots : TV (2200 µS.cm^{-1}) (Figure.5 to 8).

The pH gives information about the nutritive elements and the risks of toxicity. It is measured for each type of soil (SA, TV, TA and ZC) and is represented in table 1.

Table I. Variation of the pH according to the depth and the types of occupation.

pH	5,9	5,6	5,2	4,2	4,3	4,2	6,2	6,4	6,6	6	5,9	5,7
deepth (cm)	0 -20	20-40	40-60	0 -20	20-40	40-60	0 -20	20-40	40-60	0-20	20-40	40- 60
Type of occupation	SA	SA	SA	TV	TV	TV	TA	TA	TA	ZC	ZC	ZC

The values of pH varies between 4.2 and 6.6. The soils are moderately acid (0 - 40cm) and very acid (40-60 cm) in SA, extremely acid in TV, slightly acid in TA and moderately acid in ZC.

The sum of the exchangeable bases (S = Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}) makes it possible to appreciate the chemical fertility which relates to the availability of the nutritive elements of the plants, the problems of toxicity and the proportions of cations on the argilo-humic complex.

Table II. Soil fertility parameters

Profils	Deepth. (cm)	C %	Organic matter %	Exchangeable bases meq.100g^{-1}				CEC	H
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	meq.100g^{-1}	%
SA	0-20	0,45	0,78	0,75	4,12	0,09	0,02	4,9 8	
	20-40	0,47	0,81	0,75	4,50	0,09	0,01	5,35	11
	40-60	0,47	0,81	1,50	4,50	0,09	0,03	6,12	13
TA	0-20	0,83	1,42	1,50	1,12	0,21	0,02	2,85	17
	20-40	2,07	3,57	1,65	0,97	0,35	0,02	2,99	14
	40-60	1,88	3,24	1,65	0,97	0,34	0,02	2,98	14
TV	0-20	2,54	4,38	4,57	4,42	0,08	0,07	9,14	13
	20-40	2,07	3,57	2,02	2,85	0,13	0,07	5,07	14
	40-60	1,69	2,92	1,87	0,67	0,17	0,01	2,72	14
ZC	0-20	3,95	6,82	1,57	0,52	0,04	0,02	2,15	4
	20-40	3,39	5,84	1,50	0,15	0,05	0,01	1,71	5

The soil content of organic matters is more important in the ZC with the higher values in the upper part of the soil (6.82 %).

The soils are very poor in organic matter: with an average of 0.80 % in the SA ; 3.32% in the deepth 20-40 and 40-60 cm of the TV and TA. But in the upper parts (0-20 cm), the soils of TA are very poor in organic matter (1.42 %) and those of TV are rich (4,38%) .

It is observed a reduction in the organic matter content of the zones closest to the sea.

According to the ionic assessment, the cations involved show a prevalence of the (Ca+Mg/K) ratio. The prevalence of the cations and the involved anions shows that ions Mg^{2+}, Cl^{-} and SO_4^{2-} are most important. The salinisation of the soil is calcic and magnesian chlorinated type. (Table III, figure 14)

Table III**.** Ionic assessment of soils

Occupation	Deepth.(cm)	Ionic assessment meq.100g^{-1}							
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
	0-20	1,2	1,8	0,40	0,40	0	0,5	66	2,430
SA	20-40	2,3	0,3	0,38	0,43	0	0,25	65	2,804
	40-60	1,7	0,8	0,40	0,55	0	0,37	66	12,897
	0-20	6,5	5	0,20	0,06	1	0,62	21	4,860
TA	20-40	3,5	7,5	0,23	0,06	2	0,37	23	6,729
	40-60	6	6,8	0,20	0,06	3	13,2	20	11,963
	0-20	1,2	1,8	0,30	0,32	4	0,5	43	11,215
TV	20-40	5	5	0,27	0,26	5	0,25	44	4,860
	40-60	3,7	5,3	0,29	0,23	6	0,5	44	6,916

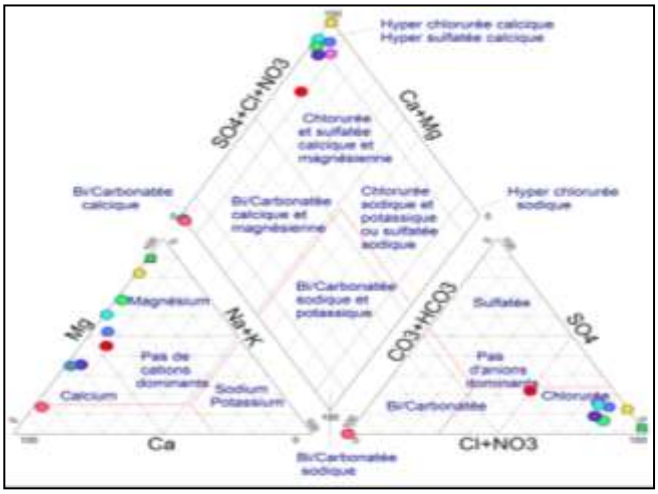


Figure 14. Diagram showing the prevalence of the ions in the study area soils

4. Discussion

The salinisation is a process of degradation of the soils whose consequences have a negative impact on the capacities to produce of soils. Several authors tried to explain the complexity and the width of phenomenon in the areas of Kaolack and Fatick (Sadio, 1991; Marius and Lucas, 1991; Bailly 1962j; Maignien et al., 1965; Bertrand and al. (1970j); Marius, 1977; Niang, 1985).

The results of the analyses indicate a spacial variability of the salinity which follows an upstream downstream increasing gradient according to the topography. The values of EC vary from 14 µS.cm^{-1} (ZC) with 3290 µS.cm^{-1} (SA). The salinisation constitutes an important phenomenon in the dry zones, it causes a degradation of the biological, chemical and physical soil properties. The consequences of this degradation is the reduction in the soil fertility which involves a reduction of the outputs of crops and sometimes a disappearance of vegetable cover. These phenomena of impoverishment of the soil are thus factors of desertification (Aubert, 1975). The damage caused by salt is more serious in hot and dry climate (Rahoui and al., 2000). The major consequence of the increase in salinity is the destruction of the intrinsic soil properties, in particular the physical properties.

Our study indicates that the rate of infiltration and the bulk density are related to the soil type (Oro and al.). The null rate of infiltration in TV is due to the soil moisture because the tests were carried out in wintry time (september 26th). In other soil types (TA, SA and ZC) we distinguish the initial rate of infiltration at the beginning of test and the rate from infiltration in permanent mode. As water fills porosity of the soil, the rate of infiltration increases to be stabilized with an eigenvalue for each soil: 0 mm.h^{-1} (TV) 0.2 mm.h^{-1} (TA), 2.4 mm.h^{-1} (SA) and 14 mm.h^{-1} (ZC). The bulk density decreased in the same direction: it is > 2.40 kg.m^{-3} in TV, 2.4 kg.m^{-3} in TA: 2.32 kg.m^{-3} in zone of SA and finally 2.12 kg.m^{-3} in ZC.

The increase of the soil bulk density in the salted zones where soils structure are destructured reduced the soil porosity which affects negatively the speed of the drainage, the availability of the air and water.

The high values of *da* indicates either the compaction of the soil or a high content of clay. In our case, it is rather the destructuring of the soil by the salinity which reduced porosity and thus increased the bulk density (*da*). The compacted soil have a high density, their rate of infiltration drops appreciabily, that is particularly notable on the clay or sandy-clay soils.

The horizons of surface are characterized by a salinity higher than the deep horizons except in SA where salt is involved in-depth by percolation waters.

Except the ZC, the soils of Ndiaffate are moderately acid to extremely acid. They have a weak fertility. In the TV and TA soils have fine textures ($\phi < 63$ µm).

They are Clay to loamy-clay, which contribute to the reduction of the soil porosity, consequently a fast saturation which reduces the infiltration of water.

In the none vegetalized and little vegetalized spots the soils are salty sulphated, sulphated acid salted and sulphated acid hydromorphic salted (Sadio, 1991). Our results show that the pH of the soils in TV and SA are respectively extremely acid and moderately acid to very acid. This acidity makes that cations such as Cl^- and Na^+ will enter competing with certain elements like K and the Mg which will be less available for the plant. And consequently the fertility of the ground remains weak.

The soils of the spots contain sodium chloride (NaCl) or sodium sulphate (Na_2SO_4), substances which will increase the salinity. However the sodium tends to be surrounded by water to be stable in the medium. The water retained by the Na^+ ions is not easily mobilizable by the plants because its mobilization requires a suction much more important. A soluble salt excess in the radicular zone blocks the absorption of water by the plants. The plants suffer from a drought due to salt.

The soils located along sea are subjects to sea intrusion which can modify their physical properties. The major consequence of the increase in salinity is the destruction of the intrinsic properties of the soil and thus leads to an agricultural production fall. Indeed, salinity delays the growth by reducing the availability of water for the plants by increasing the concentration of certain elements such as Cl^- and Na^+ which have a toxic effect on the vegetable metabolism.

The process of salinisation of the grounds of Ndiaffate results from the presence of the hydrographic network from Sine Saloum river and the anthropic actions.

5. Conclusion

Our results show that electric conductivity, the bulk density and the rate of infiltration varie according to the gradient of salinity.

The salinisation of the soil involved the modification of their physical properties and consequently an increase of their bulk density following the reduction of their porosity and the reduction the infiltration rates. In the TV where the impact of salinity is more marked the rate of infiltration is null.

The practice of salt production has as a major consequence like the increase in salinity, the destruction of the intrinsic properties of the soil and the reduction of the agricultural surfaces.

Besides this behavior of sodium, clay textures with loamy-clay also contribute to the reduction of the soils porosity, consequently a fast saturation which could reduce the infiltration of water, it is the case of the soils at the TV zone. The electric conductivity (EC), the apparent density and the rate of infiltration varie according to a gradient of salinity.

This study made it possible not only to establish a gradient of salinity but also to put forward the state of advanced degradation of the grounds in particular because of salt production.

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