Computational Water, Energy, and Environmental Engineering, 2022, 11, 116-133
https://www.scirp.org/journal/cweee
ISSN Online: 2168-1570
ISSN Print: 2168-1562

Evaluation of the Effect of Different Leaching Fractions on Soil Salinity

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How to cite this paper: Ndiaye, M., Diop, L., Sarr, A., Wane, Y.D., Diatta, I. and Seck, S.M. (2022) Evaluation of the Effect of Different Leaching Fractions on Soil Salinity. *Computational Water, Energy, and Environmental Engineering*, **11**, 116-133.
https://doi.org/10.4236/cweee.2022.114007

Received: August 9, 2022
Accepted: October 25, 2022
Published: October 28, 2022

Abstract

Soil salinisation is one of the main problems in agriculture. To overcome this problem, different methods of managing saline soils are used, including the practice of leaching under irrigation. The objective of this study is to evaluate the effect of different leaching fractions on saline soils in the Nguetiouro lowland in Gandiolais, in Senegal. For this purpose, a completely randomized block set-up has been implemented with three treatments, repeated three times: 1) T0 equivalent to a water volume input equal to the daily reference evapotranspiration (ETo), 2) T1 equivalent to a water volume input equal to the daily reference evapotranspiration plus 10% ETo of leaching and 3) T2 equivalent to a water volume input equal to the daily reference evapotranspiration of the medium plus 20% ETo of leaching. The results showed that leaching has an effect on soil salinity. The initial soil salt storage was reduced by 22.5%, 33.5%, and 50.6% in the first soil horizon, from 0 to 10 cm and by 14%, 35.3%, and 45% at depth from 10 to 30 cm for T0, T1, and T2, respectively. The fitting of simple linear regression models between electrical conductivity and soil moisture showed a negative linear relationship as a function of leaching fractions. The coefficients of determination of model are 0.74 for T0, 0.84 for T1 and 0.86 for T2 in the first soil horizon and 0.63 for T0, 0.83 for T1 and 0.88 for T2 in the depth form 10 to 30 cm. These results can be of great importance in the fight against soil salinity.

Keywords

Leaching, Salinity, Evapotranspiration, Gandiolais, Senegal

1. Introduction

Salinization is a major global environmental problem. It reduces agricultural and food production and affects people's livelihoods. According to [1], salinization affects more than 1100 Mha of land, most of it in arid and semi-arid areas. It is a phenomenon that results in the accumulation of soluble salts in the soil. It is actually an excess of salts in the soil, particularly sodium, which causes the degradation of the biological, chemical and physical properties of the soil which lead to a decrease in soil fertility and the disappearance of natural vegetation cover [2].

Salinization can be of natural or anthropogenic origin. Indeed, natural or primary salinization is the most widespread in the world. It affects nearly 80% of salinized land [3] as a result of the progressive accumulation of ions necessary for the formation of soluble salts resulting from the alteration of certain sedimentary, volcanic and hydrothermal rocks [4]. Furthermore, nearly 77 million hectares of irrigated land in the world are affected by socalled secondary salinization due to anthropogenic activities, particularly agriculture [5]. This type of salinization occurs when significant quantities of salt-laden water are brought in through irrigation [5].

In fact, only 20% of the world's cultivated land is irrigated, but it produces 40% of the world's crop. On the other hand, almost a third of this land is less productive due to inadequate irrigation, which causes waterlogging and salinization [6]. Indeed, under the constraint of water resource shortages and the use of marginal quality water, particularly in arid and semi-arid areas, significant amounts of salt-laden water are brought in through irrigation. Thus, without an adequate drainage system for leaching and removal of salts, these inputs lead to an increase in soil salt content [5].

In Senegal, the proportion of land degraded by salinization represents about 6.8% of agricultural land [7]. This salinization is favoured on the one hand by the country's topography, which is largely flat and reduces natural soil drainage, and on the other hand by Senegal's position as the downstream of several major rivers and deltas [8]. There is also the inappropriate use of land in irrigated areas, notably the Niayes zone, and the advance of the saline wedge in coastal areas as a result of excessive abstraction from coastal aquifers [2] [9].

The ecological zone of the Niayes is an area of high agronomic value. It provides 80% of the country's horticultural production [10]. However, it is affected by salinization, which negatively impacts agricultural ecosystems [11] [12] [13]. Indeed, the coastal part of the Niayes area is subject to high salinization [12]. In addition, progressive salinization is noted in the lowlands due to the lowering of the water table and the intrusion of sea water. In addition, there are significant inputs of sea spray in areas close to the ocean, particularly in Saint-Louis, where the phenomenon is amplified by the effects of the Diama dam and the relief canal opened on the Langue de Barbarie [11].

Given this situation, management and recovery methods must be undertaken to maintain the productivity of these saline soils at an acceptable level. Thus, several management methods for saline soils have been developed, ranging from so-called biological methods based on organic amendments and phytoremediation to so-called classical methods, notably chemical approaches and hydraulic approaches such as leaching [14].

Leaching is used to move soluble salts from the soil solution to the depths in order to reduce their toxicity to plants, to lower the osmotic pressure in the soil solution and to limit soil destructuring [15]. In this respect, several authors [16] [17] assert the ability of leaching to reduce the stock of salts in the soil. According to [18], flooding of a clayey-sandy soil can reduce the initial salt stock in the soil by up to 59%. [19] showed that leaching with a drip system on a saline loam soil, allows the removal in the root zone of the salt content of the soil by 64.4% compared to its initial state. [20] also asserted the ability of leaching on a saline loamy soil to decrease the amount of sodium in the soil solution of the soil.

In this context, this study is conducted to assess the effect of different leaching fractions on saline soils in the Nguéthiouro basin. Specifically, the study aims to 1) characterize the soil and water in the basin, 2) assess the effect of leaching on soil salinity and 3) evaluate the relationship between soil moisture and salinity as a function of leaching fractions.

2. Material and Method

2.1. Presentation of the Study Area

The study was conducted at Nguétiouro located at the north-eastern end of the Niayes area, in the commune of Ndiébène Gandiole in Senegal. It lies between 16˚28'30" and 16˚24'05" in west longitude and 15˚50'20" and 15˚56'10" in north latitude. The Niayes area is located along the northern Senegalese coastline known as the Great Coast. It is an agro-ecological zone with a strip 180 km long and 5 to 30 km wide (**Figure 1**) [12] [21].

The climate in the Nguétiouro area is Sahelian. The warmest average monthly temperature is around 27.5˚C and occurs in July and August. Rainfall is low (350 mm per year in the northern part of the Niayes) and is dictated by the monsoon coming from the south from the St Helena high pressure system during the winter months. The morphology of Nguétiouro consists of a series of dunes alternating with inter-dune basins. In addition, the soils are predominantly tropical ferruginous, while at the bottom of the depressions, the soils are clayloam and clay-loam [22].

2.2. Experimental Set-Up

A completely randomised block design was used to conduct the study. It consists of a 100 m^2 (10 m × 10 m) plot composed of nine elementary plots (three replicates of three treatments) of 4 m^2 (2 m × 2 m) each. Between the elemental plots, spacings of 1.5 m in width were set aside. The leaching treatments were applied to bare soil at a daily frequency. The leaching fractions were of three levels: 1) T0 which corresponded to the daily reference evapotranspiration (ETo), 2) T1 to the reference evapotranspiration plus 10% leaching and 3) T2 to the reference evapotranspiration plus 20% leaching (**Figure 2**).

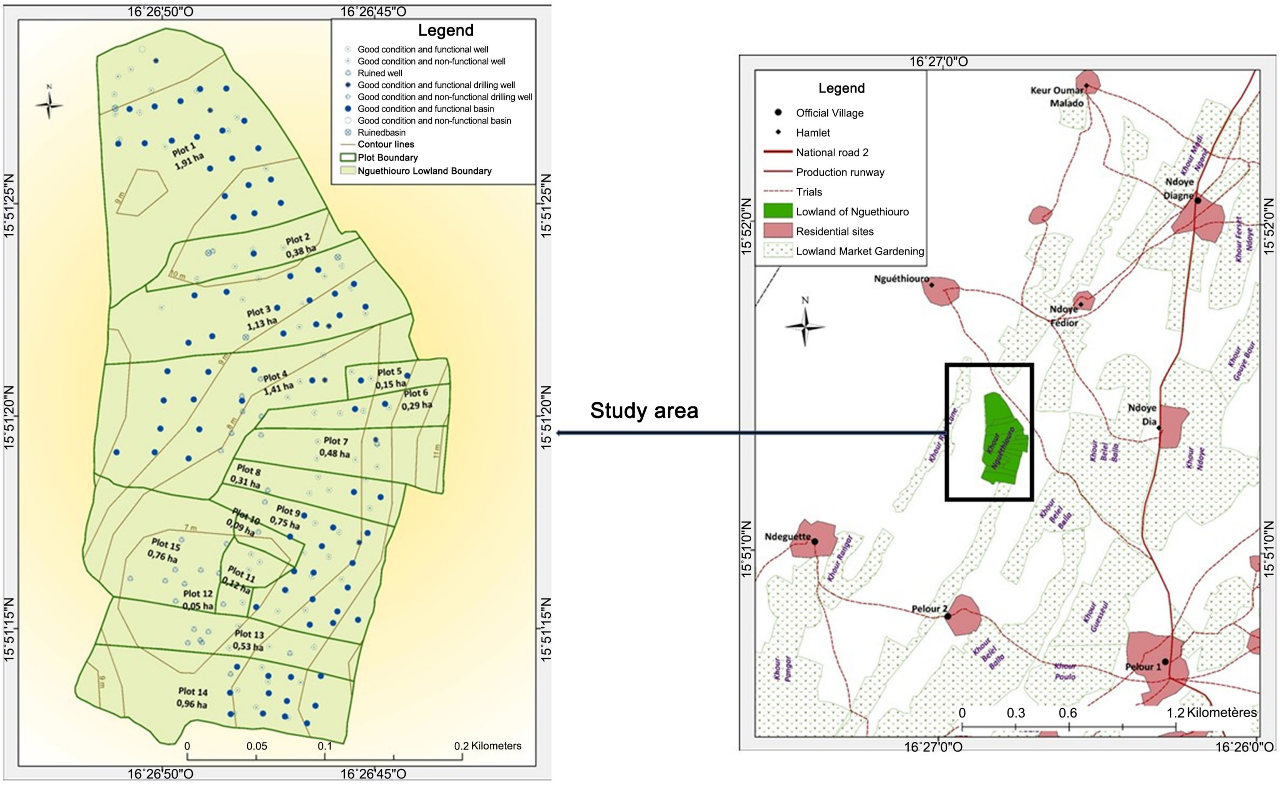


Figure 1. Location of area of study.

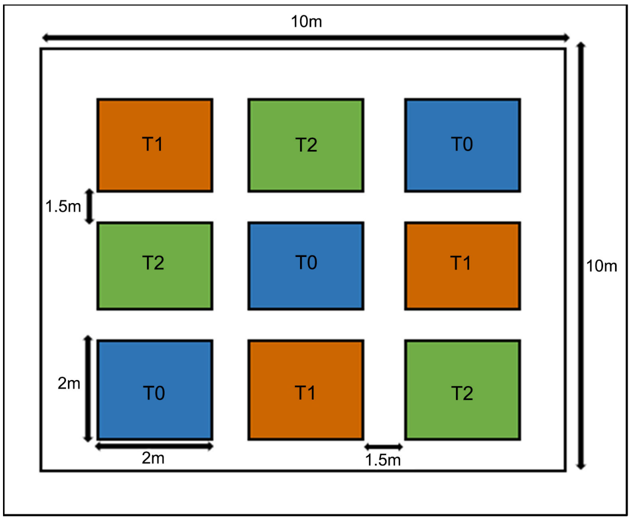


Figure 2. Experimental setup.

2.3. Determination of Leaching

2.3.1. Assessment of Reference Evapotranspiration (ETo)

The determination of the leaching fractions required regular monitoring of the daily reference evapotranspiration (ETo) of the environment and associated calculations over the entire study period. Thus, climatic data from the meteorological station of Lake Kalassane were used to evaluate ETo of the environment according to the Penman-Monteith method described in Equation (1).

$$\text{ETo}=\frac{0.408\Delta\left(\text{Rn}-\text{G}\right)+\dfrac{900}{\text{T}+273}\text{u2}\left(\text{es}-\text{ea}\right)}{\Delta+\gamma\left(1+0.34\text{u2}\right)} \tag{1}$$

where ETo is the reference evapotranspiration (in mm/day), Rn is the global radiation (in MJm^2/day), G is the soil heat flux (in MJ/m^2/day), T is the daily mean air temperature at a height of 2 m (in ˚C), v is the wind speed at a height of 2 m (in m/s), es the saturation vapour pressure (in kPa), ea the vapour pressure at temperature T (in kPa), Δ the slope of the saturation vapour pressure curve (in kPa/˚C), γ the psychrometric constant (in kPa/˚C) and 900 a constant for a daily time step.

2.3.2. Estimation of Leaching Rates

The applied leaching fractions were calculated on the basis of the ETo of each previous day. They are represented by the following Equations (2)-(4)

$$\text{T0}=\text{ETo} \tag{2}$$

$$\text{T1}=\text{ETo}+\left(\frac{\text{ETo}*10}{100}\right) \tag{3}$$

$$\text{T2}=\text{ETo}+\left(\frac{\text{ETo}*20}{100}\right) \tag{4}$$

where ETo is the reference evapotranspiration in mm, T0 the first leaching fraction in mm, T1 the second leaching fraction in mm and T2 the third leaching fraction in mm.

Following the estimation of the leaching rates, the results obtained were converted into litres and then extrapolated to the plot area (4 m^2) to obtain the volume of water to be applied to each elementary plot. The application of the leaching doses was carried out using a 10 L graduated bucket, which served as a tool for measuring the volume of water to be applied, and a watering can to ensure the correct distribution of the leaching fraction on the plot to be treated.

2.4. Determination of the Electrical Conductivity of Irrigation Water

The determination of the irrigation water electrical conductivity (EC) were determined weekly over the entire study period. Indeed, in-situ analyses of the EC of the water were carried out using a portable conductivity meter (Brand: METTLER TOLEDO 8603 Schwerzenbach, Switzerland) and were performed on the irrigation well water. The interpretation of EC values is taken from [23] (Table 1).

Table 1. Assessment of irrigation water salinity.

Water salinity	EC dS/m	TDS mg/l
None	<0.7	<450
Mild to moderate	0.7 - 3.0	450 - 2000
Severe	>3.0	>2000

2.5. Determination of Soil Electrical Conductivity

The electrical conductivity of the soil was assessed in the laboratory by the dilute extract method. A soil to water ratio of 1:5 was used according to the [24] protocol. First, soil samples were taken along the vertical axis of each unit plot using an Edelman auger. The samples were taken at two depth levels (0 - 10 cm and 10 - 30 cm). A total of 144 soil samples were collected, 18 samples per week. The samples taken during the first week were used as baseline samples to characterize soil salinity. For each elementary plot and for each depth level, two separate soil samples were taken and mixed in a bucket to form a composite sample. Following homogenization, the composite samples are placed in airtight plastic bags and kept cool in a cooler for laboratory analysis.

After the soil samples are taken, they are air-dried and then sieved through a 2 mm mesh. In addition, for each sample, 10 g of soil is removed with a spatula and added to 50 ml of distilled water in a 150 ml polyethylene bottle. The suspended mixture was kept at room temperature and shaken after 2 hours. The final step was to decant the mixture and extract the supernatant for electrical conductivity evaluation using a conductivity meter. The results are interpreted according to the ranges proposed by [25] (**Table 2**).

2.6. Determination of the Sodium Absorption Rate (SAR) of Soil

The Sodium Absorption Ratio (SAR) of the soil was tested and required the laboratory determination of exchangeable cations (Na^+, K^+, Ca^{2+}, Mg^{2+}). In fact, samples were taken in the same way as described above for the evaluation of the soil EC. In total, six soil samples were taken. The samples were taken from three of the nine elementary plots according to the treatment received (T0, T1, T2). The determination of exchangeable cations was carried out in the soil laboratory of ISRA in Saint-Louis using the ammonium acetate method. Indeed, the soil is leached with a 1 mol ammonium acetate solution. Then the percolate is collected in a 50 ml volumetric flask and supplemented with 1 mol ammonium acetate for the determination of exchangeable cations by flame atomic absorption spectrometry. The SAR is given by Equation (5).

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{1}{2} * \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)}} \tag{5}$$

Table 2. Assessment of soil salinity.

Electrical Conductivity (dS/m)	Soil
0 - 2.0	Non-saline
2.1 - 4.0	Slightly salty
4.1 - 8.0	Moderately salty
8.1 - 16.0	Highly saline
>16.1	Extremely salty

Source: [25].

where SAR is the sodium absorption rate in (meq/100g), Na^+ is the sodium concentration in (meq/100g), Ca^{2+} is the calcium concentration in (meq/100g) and Mg^{2+} is the magnesium concentration (meq/100g).

The interpretation of the sar results was carried out according to [26] (**Table 3**).

2.7. Assessment of the Effect of Leaching on Soil Salinity

The evaluation of the effect of the different leaching fractions on soil salinity was carried out by calculation through the estimation of the rate of variation of soil salinity. Indeed, it was carried out on the basis of the evaluation of the variation of the electrical conductivity of the soil during the study period. Thus, the data from the EC analyses were used and the initial soil salinity was considered as a reference condition for estimating the evolution of the salt stock according to the leaching treatments. Indeed, on each horizon (0 - 10 cm and 10 - 30 cm), the rate of change of soil EC is calculated for the different leaching treatments and then compared to the initial state of soil salinity to estimate the effect of leaching on soil salinity.

2.8. Assessment of the Relationship between Salinity and Soil Moisture

2.8.1. Determination of Soil Moisture

Soil moisture analyses were carried out in the laboratory using the gravimetric method on a weekly basis. A total of 144 soil samples were taken and analyzed at a rate of 18 samples per week. The samples were taken from the depth profile of the soil on the 0 - 10 cm and 10 - 30 cm horizons. Glass capsules were used for weighing and drying the samples. Weighing was carried out using a 0.1 g precision balance. Similarly, an oven heated to 105˚C for 4 hours was used for drying. Thus, for each sample, a repetition of two weighings is made: 1) a first weighing of the wet mass of the sample and 2) a second weighing of the dry mass of the sample after the drying in the oven. Thus, the water content of the sample is obtained as a result of the ratio between the water mass of the sample and the dry mass of the sample (Equation (6)).

$$H = \frac{m_{hum} + m_{sec}}{m_{sec}} \tag{6}$$

Table 3. Assessment of soil absorption rate (SAR).

Soil sodicity	SAR (meq/100g)
Very low	<8
Low	8 - 13
Moderate	13 - 30
Severe	30 - 70
Very severe	>70

Source: [26].

where H is the water content (%), m_{hum} is the mass of the wet sample (g) et m_{sec} the mass of the dry sample (g).

2.8.2. Assessment of the Relationship between Soil Moisture and Salinity

To assess the existence of a relationship between salinity and soil moisture, simple linear regression models were fitted to the EC and soil moisture data at the 5% significance level. For each model, EC represented the variable to be explained and soil moisture as a function of treatments, the explanatory variable.

3. Results and Discussion

3.1. Water and Soil Characterization

3.1.1. Salinity of Irrigation Water

Irrigation waters naturally contain mineral salts at defined composition and concentrations. However, in this study, in situ salinity analyses were carried out on irrigation waters through the evaluation of electrical conductivity. The result is presented in Table 4. The analysis of the electrical conductivity of the irrigation well water indicates a slight salinity of the latter, averaging 2.283 dS/m. A similar result was reported by [11]. This slight salinity of the groundwater noted in the basin is probably related to the nature of the water table. Indeed, this groundwater belongs to the Quaternary sands water table, which, on the one hand, suffers from overexploitation marked by a progressive drawdown in depth of its piezometer and, on the other hand, from the saline intrusion of sea water [11]. This phenomenon of saline intrusion can sometimes extend several kilometers inland. Thus, it spreads salt water over the land, resulting in the contamination of groundwater near the sea.

However, the use of this water in irrigation is in principle without consequences on the soil and crops as it is below the salinity threshold of irrigation water (3 dS/m) retained by FAO [23]. For example, [27] confirmed that the irrigation water salinity level of 3 dS/m can ensure good yield of tomato when the irrigation rates are daily. Similarly, [28], who tested several levels of irrigation water salinity combined with different frequencies on a silty-clay textured soil, indicates that irrigation with slightly salty water at a high frequency is favourable for good plant development.

Although irrigation with moderately salty water can be practiced, special attention is needed especially in conditions of high evaporation where irrigation is intermittent for fine-textured soil [29]. In this sense, irrigation management techniques with salty water have been proposed by researchers [20] [27]. Thus,

Table 4. Irrigation water and soil test results.

EC (water)	EC (soil)		SAR	Na^+	K^+	Ca^{2+}	Mg^{2+}
dS/m	Horizons	dS/m			(meq/100g)		
2.283	0 - 10 cm	3.65	3.21	2.22	16.69	7.34	7.35
	10 - 30 cm	2.72	3.29	7.66	1.00	14.99	7.13

based on the sensitivity of plants to salinity at the growth stage, researchers suggest the use of fresh water at the initial stage of plant growth. A mixture of agricultural drainage water with good quality irrigation water is also considered as an alternative as well as alternating good quality irrigation water with brackish water [27] [30].

3.1.2. Soil Salinity

The results of the soil EC analyses (**Table 4**) indicate a generally light soil salinity. However, a difference in salinity characterized by an ascending vertical gradient is observed on the soil profile. The spatial distribution of soil salinity is also marked by heterogeneity between the different treatments. The EC of the surface horizon (0 - 10 cm) averages 3.65 dS/m while that of the deep horizon (10 - 30 cm) is 2.72 dS/m (**Table 4**). On the other hand, the soil EC is 3.12 dS/m in T0, 4.38 dS/m in T1 and 3.84 dS/m in T2 (**Figure 3**).

These results corroborate those of [11], who prove the existence of slightly salty soils in the lowlands near the ocean in the Niayes of Saint Louis.

The origin of salt in the area could be attributed to the climatic conditions of the environment and the estuarine position of the Gandiolais area. Indeed, the area has suffered a rainfall deficit marked by a considerable decrease in annual rainfall, which fell from 684 mm in 1960 to 271 mm in 2009 [31]. In addition, combined with other deleterious phenomena, notably the opening of the rift and the rise of the salt wedge, the area is facing phenomena of transport by mass flow of soluble salts from the soil solution to the surfaces, thus favoring the concentration and accumulation of salts after water evaporation [12].

The difference in salinity noted on the soil profile has already been observed by [12] [13]. It would be due to the dynamics of the groundwater table and the high evaporation of the environment [32]. Indeed, in environments where the water table is shallow, notably in the Niayes area [33], soluble salts are rapidly put back into movement in the whole soil profile by the rise of the water table or

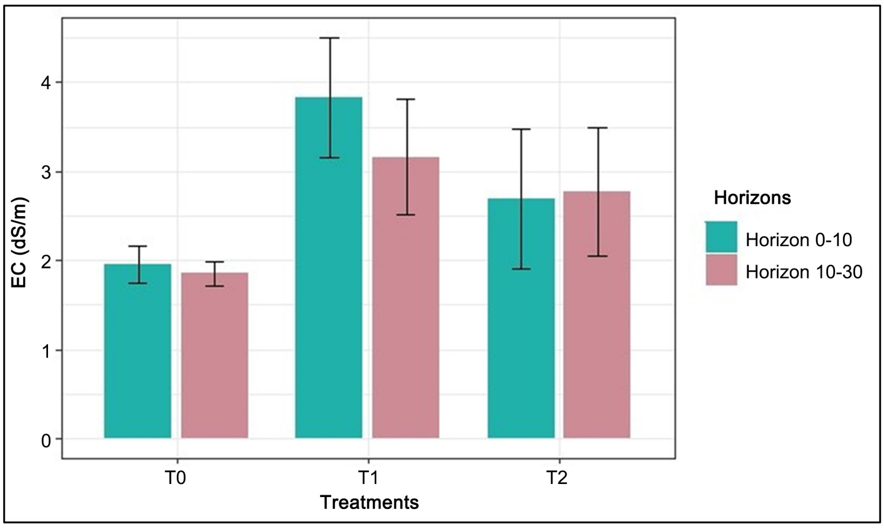


Figure 3. Initial soil salinity status.

by capillary action, due to direct evaporation or through vegetation [21]. Consequently, the concentration of salt varies from one horizon to another in the same profile as a result of cation exchange reactions between the soil and its solution, but also as a result of the dissolution rates and speeds of the various ions and salts [21].

The heterogeneity of the spatial distribution of salinity can be explained by the topography which influences the natural leaching of salts from the soil, but also the transfer of solutes. In addition, vegetation can also act as an agent in the spatial distribution and modification of the soil due to surface modifications caused by shade and the level of evapotranspiration on the one hand, and modifications at the soil interface influenced by plant roots and contributed organic matter on the other [34].

Although salinization reduces soil and crop productivity, lower soil salinity is not a limiting factor for plant development. For example, [35] evaluated the performance of onions under saline stress. The results showed that growth and bulb yield of cultivars were only affected at a salinity threshold of 4 dS/m. The same experiment repeated on tolerant cultivars of safflower (*Carthamus tinctorius L.*) indicated an inhibition of seedling growth at a salinity threshold of 5.1 dS/m.

3.1.3. The Rate of Sodium Uptake from the Soil

The richness of the soil absorbing complex in sodium ions and the associated risks of physical degradation are characterized by the soil sodium absorption rate (SAR).

The SAR describes the imbalance in the soil absorption complex between divalent cations (calcium and magnesium) and sodium [5]. It also makes it possible to define, at a threshold value, the soil sodicity term [36]. In this study, the results of the soil SAR assessment indicate a low sodium uptake rate for both horizons: 1) 3.21 meq/100g for the 0 - 10 cm horizon and 2) 3.29 meq/100g for the 10 - 30 cm horizon. This low level of exchangeable sodium is justified by the abundance of divalent cations (Ca^{2+} and Mg^{2+}) on the absorbing complex. Calcium and magnesium are respectively estimated at 7.34 and 7.35 meq/100g for the 0 - 10 cm horizon and at 14.99 and 7.13 meq/100g for the 0 - 30 cm horizon, while sodium and potassium are respectively estimated at 2.22 and 16.69 meq/100g for the 010 cm horizon and 7.66 and 1.00 meq/100g for the 10 - 30 cm horizon. The simple soil facies illustrated by the piper diagram (**Figure 4**) shows this dominance of divalent cations (Ca^{2+} and Mg^{2+}) over monovalent cations (Na^+ and K^+). It should be noted that weakly hydrated ions, in this case Mg^{2+} and especially Ca^{2+} are more energetically retained at the absorbing complex than strongly hydrated cations such as K^+ and Na^+ [13].

Calcium is naturally present in arid and semi-arid areas due to relatively low leaching. In contrast, in coastal areas, this abundance is explained by the nature of the $CaCO_3$-rich parent material [37]. However, in Gandiolais, described as a carbonate environment [13] dominated by sandy soils [11] [12], the low rate of sodium uptake could be related to the nature of the soil. Indeed, starting from

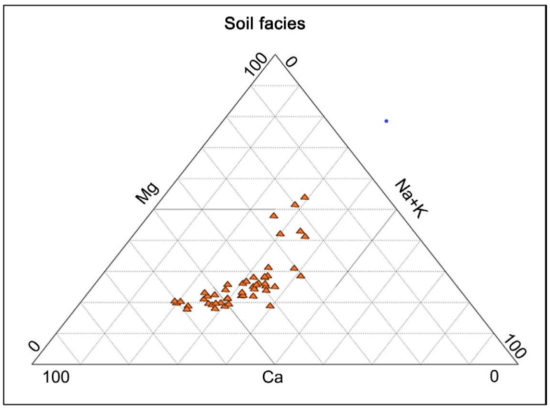


Figure 4. Simple soil facies.

the saline character of the soil, which is less sensitive to destructuration due to its flocculating power and the sandy texture of the soil, residual or irrigated sodium ions are likely to be leached deep into the soil during irrigation or rainy seasons.

3.2. Effect of Leaching on Soil Salinity

Figure 5 and **Figure 6** show the evolution and variation of soil electrical conductivity (EC) as a function of the leaching treatments, respectively.

Overall, the soil EC shows a decrease for all treatments with notable differences between the horizons (0 - 10 cm and 10 - 30 cm). In the 0 - 10 cm horizon (**Figure 5(a)**), the most significant decrease in salinity was recorded in Q2. The EC values decreased from 3.94 dS/m to 1.946 dS/m (**Figure 6(a)**), *i.e.* a decrease in soil salinity of 50.60% (**Table 5**). In T1 the initial soil stock was reduced by 33.54%. The soil EC decreased from 4.77 dS/m to 3.2 dS/m. T0 gave less response compared to the other leaching fractions. Soil salinity decreased slightly from 2.245 dS/m to 1.74 dS/m, a rate of change of 22.49%.

At the level of the 10 - 30 cm horizon (**Figure 5(b)**), the same downward trend is noticed except that at this level, the rate of change recorded in Q1 is slightly higher compared to the 0 - 10 cm horizon, *i.e.* 1.49% higher. In Q2 the EC decreased by 45.05% with EC values decreasing from 3.743 dS/m to 2.057 dS/m (**Figure 6(b)**). At T0 the initial soil salt stock was reduced by only 14%. The soil EC decreased from 2 dS/m to 1.72 dS/m. Furthermore, the comparison between the rates of change recorded in the two horizons shows a more pronounced response to the leaching treatments in the surface horizon than in the soil depth (10 - 30 cm horizon).

The results showed that leaching reduced soil salinity. This reduction could be attributed to the nature of the soil itself. Saline soils are known to have good hydraulic conductivity facilitating leaching due to their structural stability. This structural stability is achieved through the high concentration of salt in the soil solution, which tends to push the adsorbed cations closer to the surface of the clay particles, thus aggregating and holding the soil aggregates together [38]. As a result, the macropores formed facilitate the flow of water and the leaching of salts into the root zone. The difference in the decrease in salt stock between treatments is related to the water volumes of the leaching fractions. [39] argued that soil salinity at shallower depths decreases as the leaching fraction increases. As noted in the assessment of initial soil salinity, the distribution of salts in the soil profile is also affected by a disparity marked by higher salinity at depth than at the surface following leaching treatments. This is due to the fact that salt moves with the water that infiltrates the soil. As a result, soil salinity becomes lower near the soil surface and increases as depth increases [39].

Table 5. Rate of change of soil electrical conductivity.

	Rate of change of EC (%)		
Horizons	**T0**	**T1**	**T2**
Horizons (0 - 10)	22.49	33.54	50.60
Horizons (10 - 30)	14	35.3	45.05

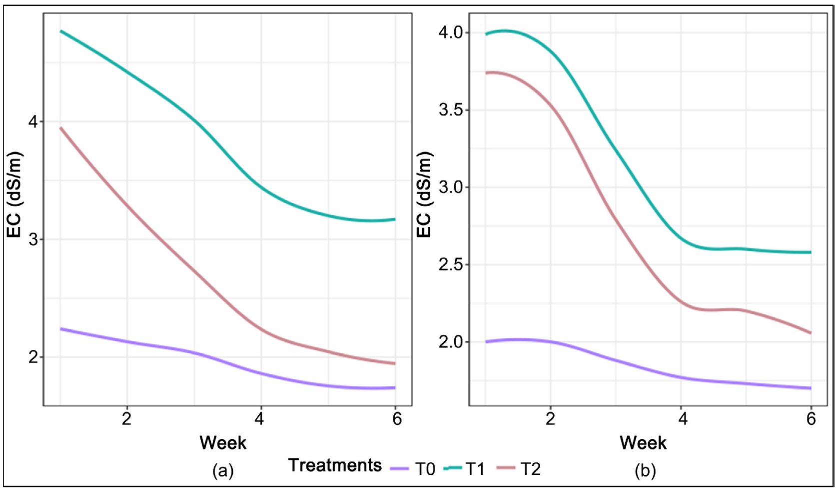


Figure 5. Evolution of soil electrical conductivity in the 0 - 10 cm (a) and 10 - 30 (b) horizon according to the treatments.

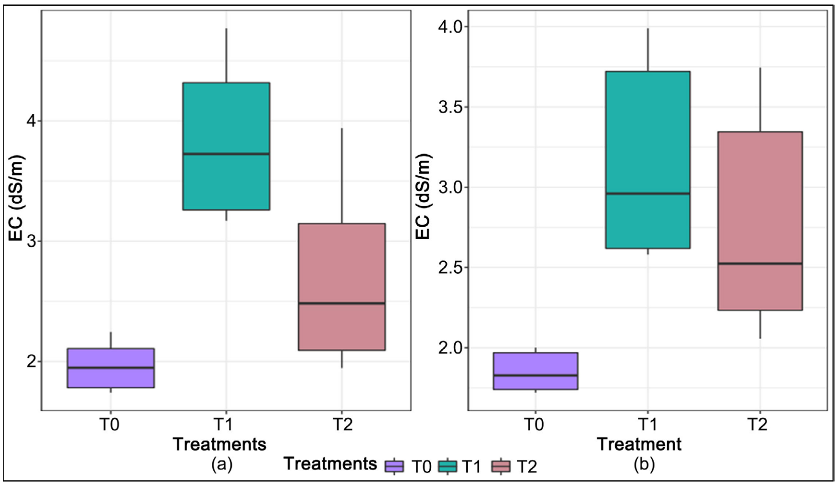


Figure 6. Variations in soil electrical conductivity in the 0 - 10 cm (a) and 10 - 30 (b) horizons according to the treatments.

3.3. Relationship between Soil Moisture and Salinity

3.3.1. Soil Moisture

The evolution of soil moisture content under the three leaching treatments (T0, T1, and T2) is illustrated in **Figure 7**. Initially, the soil moisture values indicate a disparity in mass water content at the soil surface and at depth. It is respectively 12.2%, 12.75% and 10.88% for T0, T1, and T2 in the 0 - 10 cm horizon (**Figure 7(a)**). In the 10 - 30 cm horizon, a much higher moisture content is initially noted compared to the 0 - 10 cm horizon, *i.e.* 15.5%, 17.81% and 14.3% for T0, T1 and T2 respectively (**Figure 7(b)**).

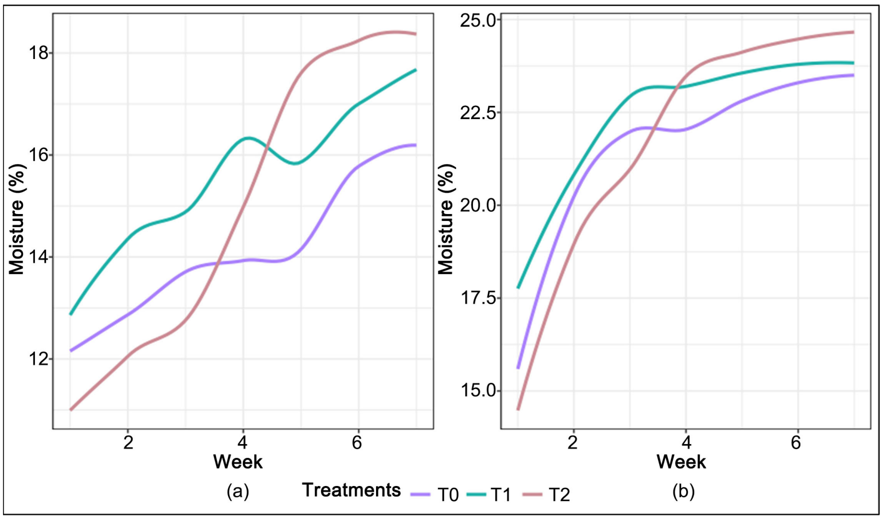
Table 6 summarizes the rates of variation of soil moisture according to the leaching treatments. Indeed, the monitoring of soil moisture (**Figure 7**) shows a clear overall increase in soil moisture content for the different horizons and according to the leaching rates applied. However, the detailed analysis of **Figure 7** indicates that the increase in soil moisture slowed down in the sixth week of leaching treatments and tended towards saturation. This trend is noted both on the 0 - 10 cm horizon and on the 10 - 30 cm horizon.

In the 0 - 10 horizon (**Figure 7(a)**), the greatest increase in soil moisture was noted with T2, with a rate of variation of 41.05% (**Table 6**), followed by T1, which showed a smaller increase in gravimetric moisture than the T2 treatment, with a rate of variation of 27.36%. T2 had a smaller increase in soil moisture content of all treatments, with a variation rate of 23.92%. In the 10 - 30 cm horizon (**Figure 7(b)**), a similar trend is noted for the leaching treatments applied. However, soil moisture is higher at depth than at the soil surface. The rates of change recorded are 33.96%, 25.25% and 42.03% for T0, T1 and T2 respectively.

The results show that the soil is likely to have a high water retention capacity. It reacted favourably to the various continuous leaching inputs throughout the study period. This can be explained by the soil properties such as texture, structure, mineralogical composition and organic matter composition. These parameters play an important role in the hydric behaviour of the soil by acting on the size of the soil pores as well as on the ability of the soil to retain water to a greater or lesser extent [40]. In addition, the difference in water content noted between the treatments is explained by the difference in the volumes of leaching fractions applied for each treatment. Indeed, the leaching rates were higher in T2 followed by T1 and T0. Thus the soil reacted according to the volumes of water applied, marked by a higher gravimetric moisture in T2, followed by T1 and T0.

Table 6. Rate of change of soil moisture.

	Rate of change of EC (%)		
Horizons	**T0**	**T1**	**T2**
Horizons (0 - 10)	23.92	27.36	41.05
Horizons (10 - 30)	33.96	25.25	42.03



(a) (b)

Figure 7. Gravimetric soil moisture evolution in the 0 - 10 cm (a) and 10 - 30 (b) horizon according to the treatments.

Furthermore, the decrease in water retention that occurred in the sixth week of treatment could be explained by the fact that the soil reached the re-wetting point from this week onwards. In addition, a difference in moisture content between the surface horizon and the depth of the soil was also noted. This can be explained, on the one hand, by the transfer of water from the soil to the atmosphere by evaporation under the effect of temperature and, on the other hand, by the infiltration and retention of water in the depths under the effect of gravity.

3.3.2. Dependence between Soil Moisture and Salinity

To assess the level of salinity influence of soil moisture in relation to leaching fractions, simple linear regression models were fitted with soil moisture and electrical conductivity data (Figure 8). In the 010 cm horizon (Figure 8(a)), the prediction results show an overall significance for all models, *i.e.* a value of 0.027 for T0, 0.01 for T1 and 0.007 for T0. Thus, the fitted regression lines show negative slopes for all treatments, indicating a decrease in salinity with increasing humidity. However, the evaluation of the coefficients of determination R^2 shows a similarity in the predictions between models T1 and T2 with R^2 values of 0.84 and 0.86 respectively. Furthermore, the models predict that the variability of soil salinity in T1 and T2 is explained by 84 and 86% respectively by the leaching treatments, whereas in T0 it is estimated at 74%.

In the 10 - 30 cm horizon (Figure 8(b)), all fitted models are also statistically significant with p-values of 0.057, 0.012 and 0.006 for T0, T1 and T2 respectively. The slopes of the fitting lines are negative indicating a decrease in soil salinity as soil moisture increases with leaching fractions. Furthermore, the coefficients of determination (0.64 for T0, 0.83 for T1 and 0.88 for T2) of the models indicate that 64%, 83% and 88% of the variability in salinity is explained by the variability in soil moisture according to the leaching treatments.

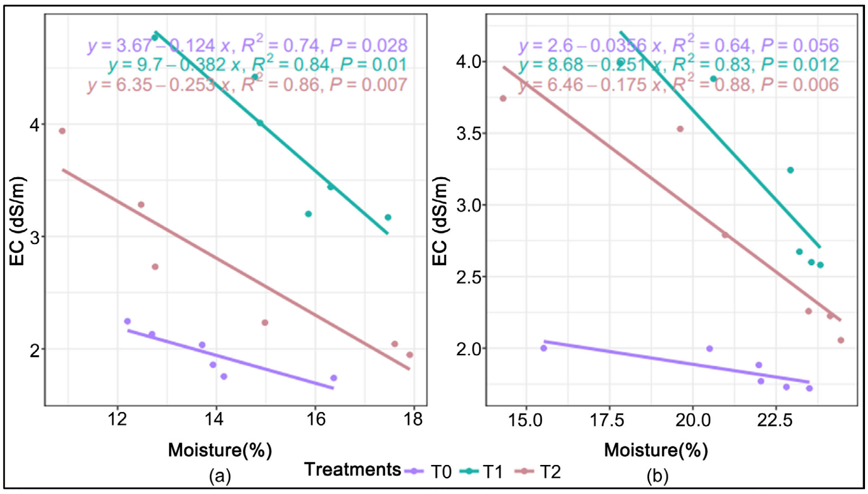


Figure 8. Gravimetric soil moisture evolution in the 0 - 10 cm (a) and 10 - 30 (b) horizon according to the treatments.

The decrease in soil salinity is inversely correlated to the moisture leaching levels. Soil salinity decreased in all treatments but at relatively different levels. This decrease is explained by the principle of leaching which emphasizes the need for water to leach salts beyond the root zone. Indeed, the leaching fraction corresponds to the part of the applied irrigation water that is leached below the root zone. In fact, the higher the leaching fraction, the more likely it is to decrease soil salinity. Furthermore, the response of the soil to leaching treatments is dependent on a number of parameters including the salinity level of the irrigation water, which must be lower than that of the soil, the hydraulic conductivity of the soil and the frequency of irrigation [38].

4. Conclusion

The study evaluated the effect of different leaching fractions on saline soils in the Nguétiouro basin in Gandiolais. A completely randomized block design was used to test three levels of leaching on soil salinity. The results show that the salinity of the water and soil in the basin is light overall. In addition, leaching has a significant effect on soil salinity. The reduction of the initial soil salt stock varies from 14% to 50.6% depending on the leaching fraction and the soil horizon. The largest decrease in salinity was recorded with the leaching treatment, which corresponded to the baseline evapotranspiration of the environment plus 20% leaching. Furthermore, the simple linear regression models indicate the existence of a linear relationship between soil moisture and salinity marked by a decrease in the latter when soil moisture increases as a result of the increase in the level of leaching. These results can be of considerable help in the management of saline soils in the Niayes zone. However, it would be interesting to test the effect of leaching on the performance of a crop grown on saline soil in the basin and the effectiveness of combining the leaching technique with the use of subsurface drains to improve soil productivity in areas with a shallow water table, notably the Niayes zone.

Acknowledgements

Many thanks to the WAGRINNOVA project (the co-innovation across scales to enhance sustainable intensification, resilience & food, and nutritional security in water-managed agricultural systems in West Africa project) for funding this research work and to its partners UGB and the GIRARDEL laboratory.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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