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Effect of Saline Water on Soil Acidity, Alkalinity and Nutrients Leaching in Sandy Loamy Soil in Rwamagana Bella Flower Farm, Rwanda

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Abstract

The necessity to saline and sodic waters is sometimes used for irrigating agricultural activities under certain circumstances, but it is important to note that the use of these waters comes with specific considerations and limitations. One way to decrease undesirable effects of sodic waters on the physical and chemical properties of soils is to apply organic and chemical amendments within the soil. This study aimed to assess the effectiveness of saline water on soil acidity, alkalinity and nutrients leaching in sandy loamy soil at Bella flower farm, in Rwamagana District, Rwanda. The water used was from the Muhazi Lake which is classified as Class I (Saline water quality). Column leaching experiments using treated soils were then conducted under saturated conditions. The soil under experimental was first analyzed for its textural classification, soil properties and is classified as sandy loamy soil. The t-test was taken at 1%, 5% and 10% levels of statistical significance compared to control soil. The results indicated that the application of saline water to soils caused an increase in some soil nutrients like increase of Phosphorus (P), Potassium (K^+), Magnesium (Mg^{2+}), Sulphur (S), CN ratio and Sodium (Na^+) and decreased soil texture, physical and chemical properties and remained soil nutrients. Consequently, the intensive addition of saline water leachates to soil in PVC pipes led to decreased of soil EC through leaching and a raiser Soluble Sodium Percentage (SSP). The rate of saline water application affected the increase accumulation of SAR and Na% in the top soil layers. The study indicated that saline water is an inefficient amendment for sandy soil with saline water irrigation. The study recommends further studies with similar topic with saline water irrigation, as it accentuated the alkalinity levels.

Keywords

Nutrients, Leaching, Saline Water, Soil Acidity, Soil Alkalinity

1. Introduction

The current irrigation water source is MUHAZI Lake. Lake Muhazi is situated in the Eastern Province of Rwanda along the northern margin of the Rwamagana District The lake has an altitude of 1443 m above mean sea level, a total catchment surface area of 829 km^2.

Most tropical African Lakes are facing problems of rapid population growth in the riparian communities, which normally discharge pollutants into the Lakes. The Lake is slightly alkaline with pH ranging from 6.2 to 8.5 with a mean value of 7.8 [1].

Application of saline water higher the salt content in soil and also increased the soil pH. According to [2] the soil pH increases with an increase in salinity, however, by using the leaching fraction technique it can be reduced significantly [3].

The quality of irrigation water might affect both crop yield, quality and physical condition of the soil, even if all other conditions and cultural practices are favourable [4].

The fate of the nutrient K^+ has received less attention than that of nitrogen or phosphorus [5]. The soil chemistry and soil fertility management mostly of K^+ and others soil macro nutrients like Ca, Mg, Na, P and N and some soil micronutrients like Na, Fe, Cu, Mn, Zn and Al^{3+} in arid and semi-arid regions are poorly studied because soils in these regions are generally well supplied with good water quality; however, soils that are intensively cropped become progressively depleted in plant-available nutrients [6]. The forms of K^+, Ca^{2+} and Mg^{2+} in soil, in order of their availability for leaching, are solution, exchangeable, non-exchangeable and mineral [6]. Exchangeable and solution forms are primarily involved in leaching. The application of K^+ fertilizers to mostly sandy soils with low clay content and small buffer capacity, in which K^+ does not interact strongly with the soil matrix, results in localized increases in K^+ concentration in the soil solution; subsequently, K^+ is leached by rainfall or irrigation water. In arid and semi-arid regions, the leaching of K^+ is enhanced by the presence of calcite and gypsum [7]. In addition to clay type and content, organic matter content and the amount of applied K^+, the leaching of K^+ is also dependent on the concentrations of other cations, especially Ca^{2+} in the soil solution. The source of Ca^{2+} for displacing K^+ is either saline solution or the weathering of soil minerals, especially those that contain gypsum and calcite [8]. Calcium is the dominant cation in soil water and at the exchange sites, and competes with K^+ for exchange sites when K^+ fertilizers are applied to the soil. The study conducted by [9] suggested that approximately 1 kg K^+ ha^{-1} was lost for every 100 mm of rainwater leached through the soil in the field, but this value may be larger if K^+ is displaced with a solution that contains a higher concentration of Ca^{2+} ions. In addition, [9] studied a sandy loam soil and measured 20 - 80 kg ha^{-1} leaching of K^+ from the soil profile over 1.5 years.

The study conducted by [10] analyzed chalky soils in laboratory and measured leaching of 9 and 74 kg K^+ ha^{-1} following leaching equivalent to 1 year of through flow in the field. It is important to note that the leaching of K^+ in arid and semi-arid regions is different to that in temperate regions. A characteristic of arid and semi-arid regions is low rainfall and the necessity of irrigation. The shortage of quality water resources is becoming an important issue in arid and semi-arid regions of the world. Ground-water is commonly the only source of irrigation, although its quality is usually low because of limited rainfall and high rates of evaporation. Thus, there is an increasing need to irrigate using low- to medium-quality ground-water. Irrigation with water in which the concentrations of Ca^{2+}, Mg^{2+}, and Na^+ are higher than those in high-quality water leads to an increase in K^+ desorption and leaching [11]. This K^+ may be more readily available to plant roots, but it is also easily leached down beyond the root zone. Recently, [11] reported losses equivalent to 90 - 300 kg K^+ ha^{-1} when 430 mm solutions containing 5 and 50 meq/L of mixed $NaCl\text{-}CaCl_2$ were applied to soil columns in the laboratory. [11] showed that irrigation water with high salinity can leach native and applied K^+ from the soil. The study conducted by [7] reported there were losses of potassium (K^+) equivalent to 29 - 387 $Kg \cdot ha^{-1}$ when 780 mm of distilled water was applied to calcite and gypsum-bearing soil columns in the laboratory. This indicates that the soil experienced leaching or runoff, resulting in the loss of potassium.

Due to the losses, an increase in K^+ concentration can be expected in groundwater within infiltration areas subjected to agricultural land use. This suggests that the potassium leached from the soil may potentially impact the quality of groundwater in areas where agricultural practices are conducted.

There is concern that the increased K^+ concentration in groundwater might lead to a breach of the drinking water limit for potassium, which is specified as 12 $mg \cdot l^{-1}$. If the concentration of potassium in the groundwater exceeds this limit, it could pose a risk to the quality of drinking water. Hence, the provided information indicates that the application of water to calcite and gypsum-bearing soil resulted in significant losses of potassium, potentially impacting groundwater quality. The concern is that elevated potassium levels in the groundwater could exceed drinking water limits, raising potential health and safety issues. Further studies and management practices may be needed to mitigate these potential risks [7]. Thus, this study was undertaken to examine effect of leaching saline water by using a laboratory column leaching procedure to examine the leaching of soil nutrients like N, K^+, Na^+, Ca^{2+} and Mg^{2+} and their effectiveness on soil acidity and or alkalinity in Bella flower farm, Rwamagana District, Rwanda.

Study Areas Description

Rwamagana district is located in Rwanda, which is situated in East Africa. Rwanda generally experiences a temperate tropical highland climate due to its elevation. The climate is influenced by its proximity to the equator and its topography, which includes mountainous regions. Rwanda usually experiences two rainy seasons each year. The long rainy season occurs from March to May, and the short rainy season is from October to December. During these periods, rainfall can be heavy and persistent, leading to lush vegetation and agricultural growth. Compared to other regions of the country, Rwamagana climate can vary with the elevation, but overall, it tends to be moderate due to its highland climate. The average temperatures usually range from 15˚C to 27˚C (59˚F to 81˚F). In higher elevations, temperatures can be cooler, especially during the evenings. The yearly range of rainfall in Rwamagana district can typically be in the range of 1000 to 1500 millimetres (approximately 40 to 60 inches) per year. This estimate takes into account both the long rainy season, which occurs from March to May, and the short rainy season, which takes place from October to December (Figure 1).

The availability of rainfall data used in this study were collected from Rwanda

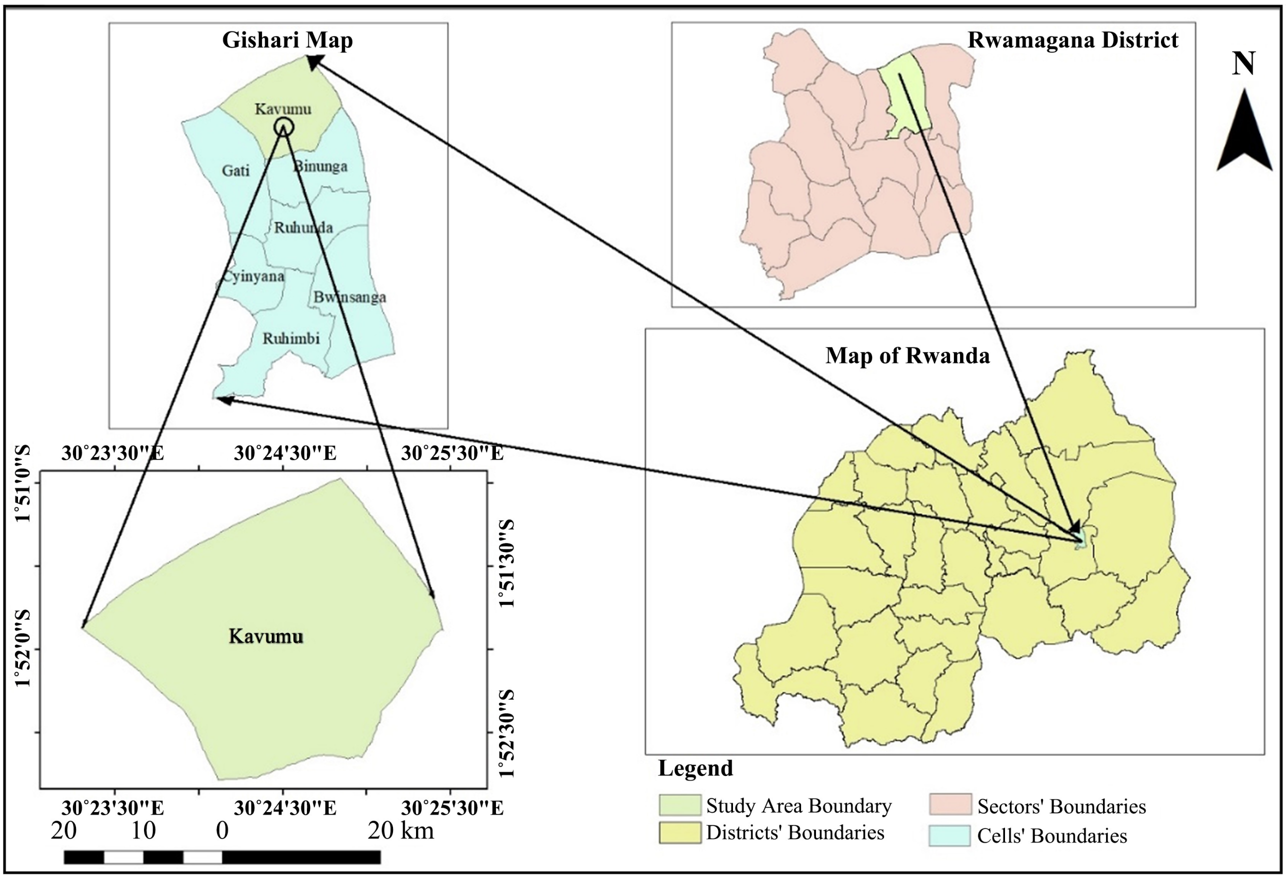

Figure 1. Topographical map showing administrative locations of Rwamagana district. Source: NISR-CGIS-NUR, 2008. CGIS: Collected Geographic Information System; NUR: National University of Rwanda; NISR: National Institute of Statistics of Rwanda.

Metrological Agency (RMA), Rwamagana district, like many other areas in Rwanda, exhibits variations in rainfall patterns due to its topography and elevation. The district's landscape ranges from higher elevations to lower-lying areas, which can influence the distribution of rainfall (Figure 2).

2. Material and Methods

2.1. Materials

Leaching is the loss of water, soluble plant nutrients from the soil, due to rain and irrigation. For the leaching experiment, the leaching columns consisted of PVC tube of 30 cm length and an internal diameter of 4.8 cm. A plastic Water tank of 20 liters was used as container to carry the whole water volume needed in the experimentation. Wooden working table, drainage outlets and plastic tubes channels were used to channel the water from the main tank to outlet. Plastic bags were in disposition to dry and then transport the soil out from the leachate.

2.2. Methods

Leaching procedure

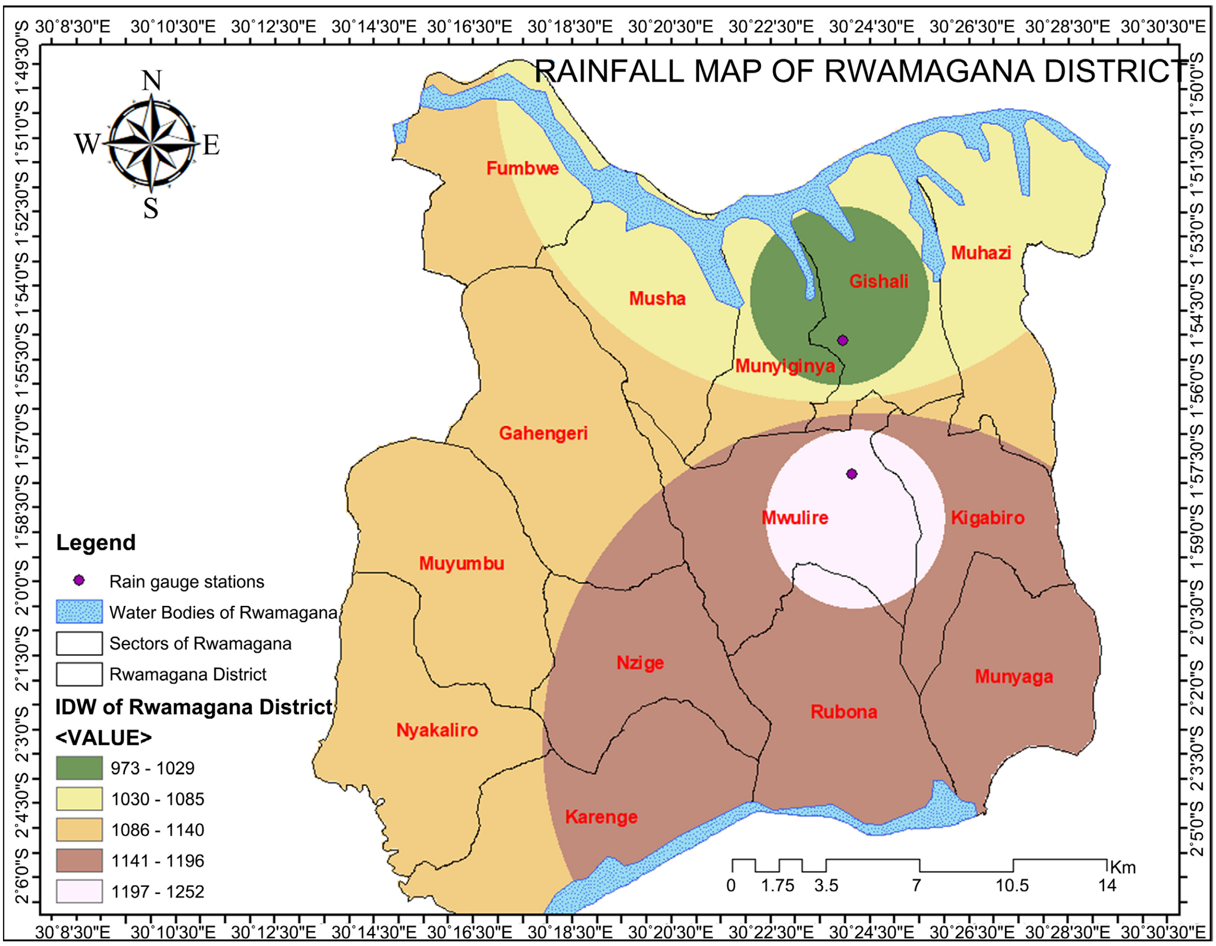

Figure 2. Spatial rainfall distribution in Rwamagana district.

Leaching, in geology, loss of soluble substances and colloids from the top layer of soil by percolating precipitation. The materials lost are carried downward (eluviated) and are generally redeposited (illuviated) in a lower layer. This transport results in a porous and open top layer and a dense, compact lower layer [12].

Leaching is one of the most practical methods for improvement of saline soils and both the quality and the quantity of leaching water play an important role in desalinization of these soils.

Leaching did not significantly alter the soil properties or plant yields in the control pots, therefore only the mean data for the controls are reported [13].

Soils were air-dried and passed through a 2 mm mesh sieve. Each water sample was poured with saline water collected from Bella flower farm, Rwamagana. The experiments were placed in leaching columns consisting of PVC tubes, 30 cm in length and an internal diameter of 4.8 cm. The mixtures were added to a height of 20 cm by uniform tapping with a wooden rod to achieve a uniform bulk density of 1.3 and 1.4 $g \cdot cm^{-3}$, depending on field bulk densities for the sandy loam and clay soil, respectively. The soil was retained by a Whatman No. 42 filter paper, which was supported on a nylon mesh base. The soil was covered with a filter paper after packing to avoid dispersion of the surface soil. Samples were collected by free drainage. Saline water was used to represent the relatively high-salinity precipitation received from rainfall the study area [14]. The leaching experiments were conducted with two replications, and a total of 4 leaching columns were set up. To maximize soil macro and micro nutrients leaching and simulate the long-term leaching of K^+ and others soil macro nutrients like Ca, Mg, Na, P and N and some soil micronutrients like Na, Fe, Cu, Mn, Zn and Al^{3+}, we added more water to the columns than the mean annual rainfall of the study area (943 mm). Regardless the water leachates characteristics that were not interested on the analysis, soil leachates were collected and analyzed for pH, EC, and soil nutrients. After leaching, the soil was again open dried for 5 days to remove totally the moisture content from the soil samples. Physical and chemical properties of soil were studied after leaching experiment as prescribed in previous paragraphs. The quantity of leached of soil macro and nutrients were analyzed through the photometric methods and AAS machine. The pH and EC were measured using pH and electrical conductivity meters, respectively. Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) in leachate were determined by titration. Sodium (Na^+) and potassium (K^+) were measured by flame photometry as prescribed by [15]. The leachates were then analyzed for soluble nutrients including majors of cations.

3. Results and Discussion

3.1. Study of Soil Physical Properties after Leaching Experiment

This topic intended to analyse soil physical and chemical properties of the collected sample soil after leaching experiment. This focused on Soil texture classification based on USDA soil texture triangle, Soil Bulk density, Soil porosity, analysis of Soil organic matter, Moisture content and Soil Structural Stability

Index and Analysis of chemical properties of Soil of Rwamagana district after leaching experiment.

Soil texture classification based on USDA soil texture triangle

After leaching experiment, soil samples were removed from PVC core cylinders and then dried for 8 days to remove moisture content by Air drying system. Thereafter, soil samples were transferred to Rwanda Standard Board Laboratory to analyse soil physical properties including soil texture and the results are showed in **Table 1**. To conduct the T-test, two parameters were used not only limited to Treated soil; which is soil that have received leachates to perform leaching experiment, but also to Control soil with is soil that never received any treatment during the experiment and their means were recorded respectively in data sheet. The DID (Difference-In-Difference) was used to compare the effect of leaching experiment on soil texture like Clay %, Silt % and Sandy % respectively. The summary of results is shown in **Table 2**.

Table 1 showed the summary of descriptive statistics of soil texture after leaching experiment. The study findings revealed that top layer soils of Bella flower farm, Rwamagana district within range of 0 - 15 cm depth and 15 - 30 cm were totally having the soil texture of Sandy Clay Loam soil with the average mean of 61%, 18% and 20% as well as 57%, 21% and 22% respectively while the depth of 30 - 45 cm showed 55%, 27% and 19% after leaching experiment. The whole sampled soil from Bella flower farm, Rwamagana indicated 57.37% of sand, 22% of silt and 20.33% of clay and based on USDA soil texture triangle, the soil changed to Sandy Clay Loam Soil after leaching experiment.

Table 1. Soil texture classification after leaching experiment.

Depth in cm	Sampling Sites	% Sand	% Silt	% Clay	Soil textural based on USDA triangle
0 - 15 cm	P1	52	22	26	Sandy Clay Loam soil
0 - 15 cm	P2	70	16	14	Sandy Loam soil
0 - 15 cm	P3	62	20	18	Sandy Loam soil
0 - 15 cm	P4	58	15	23	Sandy Clay Loam soil
Average		***61***	***18***	***20***	***Sandy Clay Loam soil***
15 - 30 cm	P1	62	18	20	Sandy Loam soil
15 - 30 cm	P2	53	30	17	Sandy Loam soil
15 - 30 cm	P3	55	21	24	Sandy Clay Loam soil
15 - 30 cm	P4	58	16	26	Sandy Clay Loam soil
Average		***57***	***21***	***22***	***Sandy Clay Loam soil***
30 - 45 cm	P1	49	30	21	Loam Soil
30 - 45 cm	P2	55	28	17	Sandy Loam soil
30 - 45 cm	P3	52	26	22	Sandy Clay Loam soil
30 - 45 cm	P4	62	22	16	Sandy Loam soil
Average		***55***	***27***	***19***	***Sandy Loam soil***
Overall Average		***57.37***	***22***	***20.33***	***Sandy Clay Loam soil***

Table 2. Estimation of soil bulk density after leaching experiment.

Variables	Stat.	Initial weight, gm	Base area, cm^2	Height, cm	Oven dry weight, gm	Volume, cm^3	Bulk density in (gm/cm^3)
After leaching	Mean	250	18.0288	20.45	142.8783	368.689	0.6927
	P50	250	18.0288	20.6	143.705	371.3933	0.6731
	Var	0.00	0.0000	8.9427	69.8329	2906.723	0.0122
	SD	0.00	0.0000	2.9904	8.3566	53.914	0.1104
	Min	250	18.0288	14.8	130.22	266.8262	0.5396
	Max	250	18.0288	25.7	154.15	463.3402	0.9369
	CV	0.00	0.0000	0.1462	0.0585	0.1462	0.1594
	N	12	12	12	12	12	12

CV: Coefficient of variation, P50: Median, Var: variance and SD: Standard deviation.

Soil bulk density of Bella flower farm, Rwamagana district soil after leaching experiment

Table 3 pertained to summary of descriptive statistics to describe the soil bulk density after leaching experiment of the soil samples collected from Bella flower farm, Rwamagana area. After leaching experiment, soil samples were dried by open air for 8 days to remove soil moisture content and then their analysis was conducted in the Laboratory of Rwanda Standard Board to determine the Soil bulk Density.

The statistical findings showed that BD ranged from 0.9369 gm/cm^3 to 0.1594 gm/cm^3 while the average mean BD for the whole soil of Bella flower farm, Rwamagana district was 0.6927 ± 0.1104 gm/cm^3. The standard deviation was 0.11 with the coefficient of variation of 0.16 which is lesser than to 0.5. It indicates that there is no appreciable change of BD of the soil after leaching experiment.

Determination of Soil porosity of Bella flower farm, Rwamagana district after leaching experiment

Table 3 pertained to summary of descriptive statistics to describe the soil porosity after leaching experiment of the soil samples collected from Bella flower farm, Rwamagana area. After leaching experiment, soil samples were dried by open air for 8 days to remove soil moisture content and then their analysis was conducted in the Laboratory of Rwanda Standard Board to determine the Soil porosity.

The statistical findings presented in Table 3 showed that Soil porosity ranged from 5.65% to 15.1% while the overall mean of soil porosity after leaching for the whole soil of Rwamagana district was found to be 10.54%. The standard deviation was 2.62 with the coefficient of variation of 0.25 which is lesser than to 0.5. It indicates that there is no appreciable change of soil porosity of the soil after leaching experiment. It is an implication the more porosity; the more soil has the ability of infiltration rate and higher hydraulic conductivity.

Table 3. Determination of soil porosity in Bella flower farm, Rwamagana district after leaching experiment.

Dependent	Stat.	W0, gm	W1, gm	W2, gm	W3, gm	W3 − W2, gm	Porosity (%)
After leaching	Mean	250	142.878	392.878	439.628	46.749	10.544
	Median	250	143.705	393.705	444.33	48.275	10.970
	Var	0	69.833	69.833	338.587	172.267	6.871
	SD	0	8.357	8.357	18.401	13.125	2.621
	Min	250	130.220	380.220	403	22.780	5.653
	Max	250	154.150	404.150	460.090	68.870	15.054
	CV	0	0.059	0.021	0.042	0.281	0.249
	N	12	12	12	12	12	12

Note: Initial weight (W0), Weight of Dry soil (W1), Weight of beaker + Dry soil (W2), Weight of beaker, soil and water added up to field capacity (W3) = (W2 − W1), Weight of water or Volume of void space in soil and then porosity (%) = (W3 − W2)/W3 * (100%); CV: Coefficient of variation, P50: Median, Var: variance and SD: Standard deviation.

Analysis of SOM, SOC Content and SSSI after leaching experiment

Table 4 pertained to summary of descriptive statistics to describe the Soil Organic Matter (SOM), Soil Organic Carbon Content (SOC) and Soil Structural Stability Index (SSSI) of Soil from Bella flower farm, Rwamagana district after leaching experiment. After leaching experiment, soil samples were dried by open air for 8 days to remove soil moisture content and then their analysis was conducted in the Laboratory of Rwanda Standard Board to determine the SOM in % or g/Kg, SOC in % based on conversion factor of 1.72 and SSSI expressed in % respectively. The summary of descriptive statistics is shown in Table 4.

Based on results presented in Table 4, the statistical findings revealed that SOM based on loss –On – Ignition (LOI) at furnace temperature of 105˚C to 450˚C and it is ranged from 79.39 $g \cdot kg^{-1}$ to 532.98 $g \cdot kg^{-1}$ while overall mean of SOM evaporated on LOI was 239.54 $g \cdot kg^{-1}$ respectively after leaching for the whole soil of Bella flower farm, Rwamagana area. The standard deviation of SOM was found to be 130.51 with the coefficient of variation of 5.45 which is greater than to 5. It indicates that there is appreciable change of Soil Organic Matter (SOM) based on Lost – In – Ignition of the soil after leaching experiment. In addition, the study findings also showed that the Soil Organic Carbon (SOC) content after leaching experiment ranged from 4.62% to 30.99% while the overall average mean of SOC was 13.93 respectively. The standard deviation of SOC was found to be 7.59% with the coefficient of variation of 0.5449 which is greater than to 0.5. It indicates that there is appreciable change of Soil Organic Carbon (SOC) content in the tested soil after leaching experiment. Furthermore, the research findings revealed that Soil Structural Stability Index (SSSI) ranged from 18.8% to 126.2% while the overall average mean of SSSI was 56.72% respectively. The standard deviation of SSSI was found to be 30.904% with the coefficient of variation of 0.545 which is greater than to 0.5. It indicates that

Table 4. SOM, SOC content and SSSI after leaching experiment.

Variables	Stat.	SOM (%)	SOM ($g \cdot Kg^{-1}$)	SOC (%)	SSSI (%)
	Mean	23.954	239.535	13.927	56.719
	Median	19.879	198.794	11.558	47.072
	Var	170.332	1703.317	57.576	955.029
	SD	13.051	130.511	7.588	30.904
After Leaching	Min	7.940	79.400	4.616	18.801
	Max	53.298	532.978	30.987	126.203
	CV	0.545	5.449	0.545	0.545
	Sum	287.442	2874.421	167.118	680.630
	N	12	12	12	12

Note: Moisture content (MC), Soil Organic Matter (SOM), Soil Organic Carbon (SOC), Soil Structural Stability Index (SSSI); CV: Coefficient of variation, P50: Median, Var: variance and SD: Standard deviation.

there is appreciable change of Soil Structural Stability Index (SSSI) in the tested soil after leaching experiment; which explain a little change in soil aggregates stability the leaching water process.

Effect of saline water leachates on Soil physical properties by T-test of equality means

To assess the effect of saline water leachates on soil physical properties, the use of t-test to perform the equality of means between two soil samples was needed to compare the mean of control and treated soil. The difference-n-difference (DID) model was adopted during the comparison. The significance test was at 1%, 5% and 10% levels. The findings from DID model are shown in Table 5 below.

After performing the t-test was through the difference in difference (DID) econometric models to test the significance factors after leaching. Except the sand soil which is not statistically significant, the percentage of silt soil have been decreased by −4.58% statistically significant with at 10% level of significance with p-value = 0.06 < 0.1 while the percentage of clay soil have been decreased by −3.83% statistically significant at 10% level of significance with p-value = 0.099 < 0.1 after leaching experiment. It is an implication that the irrigation water normally does not affect the soil texture in nature, like sand soil on top layers rather it affects later the soil chemical composition. As per [16], it is confirmed that In this experiment, the minerals leaching on the arable layers is higher that bottom layers of soil. Refer to study findings conducted by [16], it was also found that under field conditions, K leaching below the arable layer increased with K rates, but the effect was less noticeable in the clay soil. Potassium leaching in a sandy clay loam soil was related to soil K contents from prior fertilizations. With no excess water, in the presence of soybean roots, K distribution in the profile was significant in the lighter textured soil but was not apparent on the heavier textured soil.

Table 5. Leaching of saline water on soil physical properties by T-test of equality means.

Effect of leaching process on soil texture by T-test of equality means						
Variables	Mean				T-test	
	Control soil	Treated soil	Difference	S.E.	T-stat	p > |T|
Sand (%)	56.833	56.650	−0.183	3.644	0.05	0.956
Silt (%)	26.583	22	−4.583	2.741	1.67	0.066*
Clay (%)	16.583	20.417	−3.833	2.494	−1.54	0.099*
Effect of leaching on soil bulk density by T-test of equality of means						
Variables	Mean				T-test	
	Controls Soil	Treated Soil	Difference	S.E.	T-stat	p > |T|
Initial weight, gm	250	250	0.000	0.000	.	.
Base area, cm^2	50.080	18.029	−32.051	0.000	1.50E+16	0.000**
Height, cm	3.983	19.617	−15.633	0.866	−18.05	0.000**
Oven dry weight, gm	128.416	143.675	−15.259	4.824	−3.16	0.0011**
Volume, cm^3	199.485	353.665	−154.180	20.43	−7.55	0.000**
BD (gm/cm^3)	1.330	0.713	−0.617	0.106	−5.84	0.000**
Effect of leaching on soil porosity by T-test of equality of means						
Variables	Mean				T-test	
	Controls soil	Treated soil	Difference	S.E.	T-stat	p > |T|
W0, gm	250	250	0.000	0.000	.	.
W1, gm	131.4158	143.675	−12.259	4.668	−2.63	0.007**
W2, gm	381.4158	393.675	−12.259	4.668	−2.63	0.007**
W3, gm	428.165	441.592	−13.427	8.117	−1.65	0.046**
W3 − W2, gm	46.74917	47.917	−1.168	6.823	−0.17	0.836
Porosity (%)	10.88517	10.751	−0.134	1.423	−0.09	0.91
Effect of leaching on soil SOM, SOC and SSSI by T-test of equality of means						
Variables	Mean				T-test	
	Control soil	Treated soil	Difference	S.E.	T-stat	p > |T|
SOM (%)	24.3040	27.4935	−3.1895	6.2280	−0.51	0.526
SOM ($g.kg^{-1}$)	243.0395	274.9346	−31.8950	62.2803	−0.51	0.526
SOC (%)	14.1302	15.9846	−1.8544	3.6209	−0.51	0.526
SSSI (%)	56.7711	65.1013	−8.3302	14.6864	−0.57	0.482

Noted that *, ** and *** correspond to 10%, 5% and 1% significance levels respectively. Note: 1) Initial weight (W0), Weight of Dry soil (W1), Weight of beaker + Dry soil (W2), Weight of beaker, soil and water added up to field capacity (W3) = (W2 − W1), Weight of water or Volume of void space in soil and then porosity (%) = (W3 − W2)/W3 * (100%). 2) Soil Organic Matter (SOM), Soil Organic Carbon (SOC), Soil Structural Stability Index (SSSI).

The results from the T-test showed that there is statistical significance difference percentage decrease, with −0.617 gm/cm^3 after leaching experiment at 1% and 5% level of significance with p-value = 0.000 < 0.05 after leaching experiment. The results from the T-test showed that, except the dry soil (W1) with p-value of 0.007 < 5%, Weight of beaker plus dry soil (W2) with p-value of 0.007 < 5% and the Weight of beaker, soil and water added up to field capacity (W3) with p-value of 0.046 < 5% which are statistically significant decreased by −12.259 gm and −13.427 gm after leaching experiment, results from the T-test showed that there is no statistical significance difference percentage increase or decrease of soil porosity after leaching experiment at 1% and 5% and 10% level of significance with p-value after leaching experiment. The greater bulk density and higher soil porosity beyond the ideal range affect negatively the plant growth and reduces the water holding capacity in the plant root zone.

The t-test was performed through the difference in difference (DID) econometric models to test the significance factors after leaching. The tested parameters were SOM, SOC and SSSI of the soil. Unexpectedly, after leaching experiment the t-test showed that there is no soil parameter tested which was statistically significant. It indicated a small percentage decrease as prescribed by difference change after leaching with −3.19% of SOM, −1.85 of SOC and −8.33% of SSSI were all both decreased from the treated soil but not statistically significant. Generally, Soil organic matter (SOM) displayed a decreasing trend to the soil pH (**Table 5**). Unexpectedly, Comparing to SOM and pH measured, the soils have experienced a slight decrease in SOM and pH in the surface horizons due to rigorous saline leaches applied to soil. Thus, our findings conflict with the research conducted by [17] who found that there was an increase in organic matter content have on golf course fairways that had been irrigated for 5 years with recycled wastewater. We note that although SOM and carbon are generally considered beneficial, some problems may arise from elevated levels, such as soil hydrophobicity and thus reduced hydraulic conductivity under certain conditions

3.2. Analysis of Chemical Properties of Soil of Bella Flower Farm, Rwamagana District after Leaching Experiment

After conducting the leaching experiment, the researcher was interested to determine chemical properties not only limited to soil micro nutrients, but also to soil macro nutrients and soil acidity, salinity, alkalinity, magnesium hazards, Kelly ratio and soluble sodium percent and there are presented and in discussed in the sub headings. Their effect on soil chemical properties was evaluated after running t-test by comparing treated soil with leachate compared to control soils.

Leachates of soil macronutrients after leaching experiment

Table 6 pertained to summary of descriptive statistics to describe the soils macro nutrients detected after leaching experiment and major cations including Nitrogen (N), Calcium (Ca), Magnesium (Mg), Potassium (K), Phosphorus (P), Carbon content and Sulphur (S) and C/N ratio of Soil from Bella flower farm, Rwamagana district after leaching experiment. After leaching experiment, soil samples were dried by open air for 8 days to remove soil moisture content and then their analysis was conducted in the Laboratory of Rwanda Standard Board to determine the N, Ca, Mg, K, P, C, S and C/N which are both expressed in ppm

Table 6. Soil macronutrients available after leaching experiment.

		N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)	C (ppm)	C/N
After leaching	Mean	0.168	49.020	1.158	1.448	0.927	36.048	0.432	5.439
	Median	0.11	50.195	1.055	1.42	0.937	31.6675	0.196	2.970
	Var	0.028	239.656	0.189	0.385	0.489	441.434	0.185	42.281
	SD	0.168	15.481	0.435	0.620	0.699	21.010	0.430	6.502
	Min	0.027	23.38	0.64	0.49	0.114	12.185	0.095	0.231
	Max	0.472	66.34	1.83	2.61	2.215	68.161	1.162	20.533
	CV	0.999	0.316	0.375	0.428	0.754	0.583	0.996	1.196
	Sum	2.021	588.24	13.9	17.38	11.123	432.574	5.179	65.263
	N	12	12	12	12	12	12	12	12

CV: Coefficient of variation, P50: Median, Var: variance and SD: Standard deviation.

except C/N ratio respectively. The summary of descriptive statistics is shown in **Table 6**.

Table 6 pertained to soil macronutrients after leaching experiment. The summary of descriptive statistics showed that N (ppm), ranges from 0.027 ppm to 0.472 ppm while the average mean concentration after leaching experiment was 0.168 ppm. The standard deviation was found to be 0.168 and the coefficient of Variation (CV) of 0.999 which is higher than 0.5. It indicates that there is a highly appreciable change of nitrogen after leaching experiment. The statistical findings also showed that P (ppm) ranges from 23.38 ppm to 66.34 ppm while average mean was 49.02 ± 15.48 ppm. The standard deviation was found to be 15.481. The coefficient of variation was found to be 0.316 which is less than 0.5. It means that there is no appreciable change of phosphorus (P) after leaching experiment. In addition, the study findings revealed that K (ppm) ranges from 0.64 ppm to 1.83 ppm while the average mean concentration was 1.158 ppm. The standard deviation was found to be 0.435 and the coefficient of variation of 0.375; which is less than to 0.5. It indicates that there is no appreciable change K after leaching experiment of the soil.

Results presented in **Table 6** showed that Ca (ppm) ranges from 0.49 ppm to 2.61 ppm while the average mean concentration of Ca was 1.448 ppm. The standard deviation was found to be 0.620 and the coefficient of variation of 0.428; which is less than to 0.5. It indicates that there is no appreciable change Ca after leaching experiment of the soil. Furthermore, the statistical findings showed that Mg (ppm) ranges from 0.114 ppm while the average mean concentration of Mg was found to be 0.927. The standard deviation was found to be 0.699 ppm and the coefficient of variation of 0.754 which is greater than 0.5. It indicated appreciable change of Mg in the tested soil after leaching experiment. The results presented in **Table 6** also showed that S (ppm) ranges from 12.185 ppm to 68.161 ppm with the average mean concentration of 36.048 ppm. The standard deviation was found to be 21.01 and the coefficient of variation (CV) of 0.583 which is greater than 0.5. It indicated that there is appreciable change of S content after leaching experiment. The study findings showed that also C (ppm) content ranges from 0.095 ppm to 1.162 ppm with the average mean concentration of 0.432 ppm. The standard deviation was found to be 0.43 and the coefficient of variation (CV) of 0.996 which is greater than 0.5. It indicated that there is higher appreciable change of C content of the soil after leaching experiment. Finally, the study findings showed that C/N ratio varied from 0.231 to 20.53 with the average mean of C/N ratio of 5.439. The standard deviation was found to be 6.502 and the coefficient of variation (CV) of 1.196 which is greater than 0.5. It indicated that there is higher appreciable change of C/N ratio in the soil from Bella flower farm, Rwamagana district after leaching experiment.

Leachates of soil micronutrients in soil after leaching

Table 7 pertained to summary of descriptive statistics to describe the soils micro nutrients detected after leaching experiment including Sodium (Na), Iron (Fe), Copper (Cu), Manganese (Mn), Zinc (Zn) and Aluminium (Al^{3+}) of Soil from Rwamagana district after leaching experiment. After leaching experiment, soil samples were dried by open air for 8 days to remove soil moisture content and then their analysis was conducted in the Laboratory of Rwanda Standard Board to determine the Na, Fe, Cu, Mn, Zn and Al^{3+} which are both expressed in ppm. The summary of descriptive statistics is shown in Table 7.

Table 7 pertained to soil micronutrients after leaching experiment. The summary of descriptive statistics showed that Na (ppm) ranges from 0.431 ppm to 2.188 ppm with the average mean concentration after leaching experiment was 1.235 ppm. The standard deviation was found to be 0.619 and the coefficient of Variation (CV) of 0.501 which is higher or equal to 0.5. It indicates that there is a highly appreciable change of Sodium after leaching experiment in the soil. In addition, the study findings showed that Fe (ppm) ranges from 89 ppm to 231 ppm with the average mean concentration of Iron of 144.167 ppm. The standard deviation was found to be 44.031 and the coefficient of Variation (CV) of 0.305 which is less than to 0.5. It indicates that there is no appreciable change of Iron

Table 7. Soil micronutrients available in soil of Bella flower farm, Rwamagana district after leaching.

Variables	Stat.	Na (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	Al^{3+} (ppm)
After Leaching	Mean	1.235	144.167	99.540	59.983	39.546	0.873
	Median	0.983	129	97.98	57.2	35.5	0.944
	Var	0.383	1938.697	179.133	810.717	455.358	0.534
	SD	0.619	44.031	13.384	28.473	21.339	0.731
	Min	0.431	89	78.94	22.18	12.14	0.078
	Max	2.188	231	116.7	114.52	78.93	1.972
	CV	0.501	0.305	0.134	0.475	0.540	0.837
	Sum	14.822	1730	1194.480	719.8	474.55	10.478
	N	12	12	12	12	12	12

CV: Coefficient of variation, P50: Median, Var: variance and SD: Standard deviation.

after leaching experiment in the soil. The study findings showed that Cu (ppm) ranges from 78.94 ppm to 116.7 ppm with the average mean concentration of 99.54 ppm respectively. The standard deviation was found to be 13.384 and the coefficient of Variation (CV) of 0.134 which is less than to 0.5. It indicates that there is no appreciable change of copper after leaching experiment in the soil.

In addition, the research findings showed that concentration of Mn (ppm) ranges from 22.18 ppm to 114.52 ppm while the average mean concentration of Mn was found to be 59.983 ppm. For consistency, the research findings showed that the standard deviation was found to be 28.47 ppm and the coefficient of variation (CV) was found to be 0.475 respectively. It also showed that Zn (ppm) ranges from 12.14 ppm to 78.93 ppm while on average, the concentration of Zn was 39.546 ppm respectively. The standard deviation was found to be 21.34 ppm and the coefficient of variation was found to be 0.54 respectively. Finally, the study finding showed that Al^{3+} (ppm) ranges from 0.078 ppm to 1.972 ppm while on average, and the concentration of Al^{3+} was found to be 0.873 ppm after leaching experiment. The study findings showed that the standard deviation was found to be 0.731 ppm and the coefficient of variation (CV) was found to be 0.837 respectively. It indicates that there is a very high appreciable change of aluminium after leaching experiment in the soil.

Effect of saline water leachates on soil chemical properties by T-test of equality means

Based on soil squeezed in core cylinder of PVC pipe, the performance of t-test was conducted and tested at different levels of significance. The T-test was performed to compare the equality of means of soil macronutrients after leaching experiment as prescribed in routine methodology adopted. Tow parameters were used not only limited to Treated soil; which is soil that have received leachates to perform leaching experiment, but also to Control soil with is soil that never received any treatment during the experiment and their means were recorded respectively in data sheet. The DID (Difference-In-Difference) and t-test were used to compare the effect of leaching experiment on soil nutrients and other chemical properties of the soil after leaching with saline water. The summary of results is shown in Table 8.

The t-test was performed through the difference in difference (DID) and t-test to test the significance factors after leaching. The tested parameters were N, P, K, Ca, Mg, S, C and C/N ratio of the soil. After running DID and PSM models, the results from the T-test showed that Nitrogen (N) in ppm decreased by −1.252 ppm statistically significant after leaching experiment with p-value of $0.000 < 0.05$ level of significance to explain that about 95% - 99% of experimented soil samples deficient N during leachates into the soils samples. According to results presented in Table 8, the t-test showed the K increased by 0.7708 ppm after leaching and this is statistically significant at 1% and 5% level of significance with p-value of p-value < 0.05 to explain that about 95% - 99% of experimented soil samples uptake K during leachates into the soils sufficiently. The research

Table 8. Effect of saline water leachates on soil macronutrients by T-test of equality means.

Effect of soil leaching with saline water on soil macro nutrients						
Variable	Control soil	Treated soil	Difference	S.E.	T-stat	p > |T|
N (ppm)	1.4175	0.1655	−1.252	0.1440	−8.69	0.000**
P (ppm)	49.8633	52.5583	2.695	7.8502	0.34	0.450
K (ppm)	0.5067	1.2775	0.7708	0.2125	3.63	0.000**
Ca (ppm)	1.29	1.1958	−0.0942	0.3124	−0.3	0.249
Mg (ppm)	0.77	1.0793	0.3093	0.2894	1.07	0.228
S (ppm)	32.8942	38.2619	5.3678	9.6486	−0.56	0.338
C (ppm)	5.1733	0.3104	−4.8629	0.5057	−9.62	0.000**
CN	3.9143	4.7444	0.8301	2.6667	0.31	0.218
Effect of soil leaching with saline water on soil micro nutrients						
Variable	Controls	Treated	Difference	S.E.	T−stat	p > |T|
Na (ppm)	0.665	1.0107	0.3457	0.281	1.23	0.0045**
Fe (ppm)	2696	130.583	−2565.42	254.862	−10.07	0.0000**
Cu (ppm)	413.25	103.965	−309.285	31.339	−9.87	0.0000**
Mn (ppm)	124.707	62.474	−62.233	30.447	−2.04	0.0193**
Zn (ppm)	67.382	47.068	−20.314	10.512	−1.93	0.0013**
Al^{3+} (ppm)	1.903	0.835	−1.068	0.3439	−3.11	0.0004**

Noted that *, ** and *** correspond to 10%, 5% and 1% significance levels; ppm: part per million.

findings are consistent with the study conducted by [18] who confirmed that soil potassium uptake from leachate irrigation causes alterations in the nutrients uptake, which are associated with alterations in nutrient ratios, which can vary significantly leading to the accumulation of some nutrients and the lack of others. In addition, the mean comparison by t-test showed that concentration of C in soil after leaching experiment decreased statistically significant by −4.863 ppm at 1% and 5% level of significance with p-value of 0.000 < 0.05 respectively. The negative and significance difference in C content is an indication that water leachates do not salts and organic matter which were retained by soil colloids during experimentation process with higher variability (abnormal) in the soil's layers explained by CV = 1.20% respectively.

After running DID, the results from the T-test showed that the content of Sodium (Na) in ppm increased by 0.35 ppm statistically significant after leaching experiment with p-value of 0.0045 < 0.05 level of significance respectively. Unexpectedly, the remaining parameters like Fe, Cu, Mn, Zn and Al^{3+} were decreased after leaching experiment. The study findings showed that, after t-test, there is statistical significance difference decrease of −2565.42 ppm with ($p < 0.001$). It showed that also Cu decreased by −309.285 ppm with $p < 0.001$ respectively. The research findings also showed that Manganese content decreased by −62.23 ppm which is statistically significant with $p = 0.0193 < 0.05$). It showed that also Zn content within the tested soil decreased by −20.31 ppm with the Zn p-value of $p = 0.0013 < 0.05$). Finally, the research findings discovered that Al^{3+} content decreased by −1.07 ppm with $p = 0.0004 < 0.001$) respectively at l samples at 1% - 5% level of significance to explain that topsoil indicated higher concentrations of soil micronutrients compared to sub soils before leaching experiment though the difference. This implied that the depositions and decomposition of organic matter were higher in the topsoil, therefore contributing to the release of micronutrients; and these findings conflict with the research conducted [19] who found that except Al^{3+} indicated higher strong variability and Zn with moderate variability; other soil micro nutrients indicted lower leaching rate across the three land uses depth (0 - 15 cm, 15 - 30 cm and 30 - 45 cm). They concluded that soil micronutrients are hardly extractable from top soil into subsurface soil layers across different land uses.

Soil Acidity, salinity, alkalinity, Kelly index and Magnesium hazards after leaching

Table 9 pertained to summary of descriptive statistics to describe the Soil Acidity, salinity, alkalinity, Kelly index and Magnesium hazards detected after leaching experiment of Soil from Rwamagana areas of agriculture sector. After leaching experiment, soil samples were dried by open air for 8 days to remove soil moisture content and then their analysis was conducted in the Laboratory of Rwanda Standard Board to determine the pH, EC, SAR, KI and MAR respectively. The summary of descriptive statistics is shown in **Table 9**.

Table 9 summarizes the descriptive statistics of pH, EC, SAR, KI and MAR of the soil after leaching experiment. It showed that, after leaching experiment, Soil pH ranges from 4.2 to 7.65 with the average soil pH after leaching was 5.98 ± 1.06. The standard deviation was found to be 1.056 and the coefficient of variation

Table 9. Soil acidity, salinity, alkalinity, Kelly index and Magnesium hazards of soil after leaching.

	Stat.	pH	EC (µS/cm)	SAR	MAR (%)	KR	SSP (%)
After Leaching	Mean	5.981	74.464	0.417	36.453	0.582	50.252
	Median	6.023	74.433	0.414	34.221	0.542	49.889
	Var	1.115	1149.883	0.048	610.684	0.137	125.734
	SD	1.056	33.910	0.220	24.712	0.370	11.213
	Min	4.195	32.963	0.139	8.270	0.180	27.981
	Max	7.648	140.618	0.912	73.399	1.521	71.712
	CV	0.177	0.455	0.527	0.678	0.636	0.223
	Sum	71.773	893.569	5.003	437.432	6.982	603.021
	N	12	12	12	12	12	12

CV: Coefficient of variation, P50: Median, Var: variance and SD: Standard deviation.

of 0.177; which is less than to 0.5 respectively. It indicated that there is no appreciable change of soil pH after leaching experiment. Results also showed that EC (μS/cm) ranges from 32.963 μS/cm to 140.618 μS/cm while the average mean conductivity 74.46 μS/cm. The standard deviation of EC was found to be 33.9 μS/cm and the coefficient of variation of 0.455; which is less than to 0.5 respectively. It indicated that there is no appreciable change of soil EC after leaching experiment.

The study findings also showed that the Sodium Adsorption Ratio (SAR) ranges from 0.1394 to 0.912 with the average mean SAR was 0.417 ± 0.22 respectively. The standard deviation of SAR was found to be 0.22 and the coefficient of variation of 0.527; which is slightly higher than to 0.5 respectively. It indicated that there is moderate appreciable change of soil SAR after leaching experiment. Results presented in **Table 10** also showed that MAR ranges from 8.27% to 73.40% while the average mean MAR was found to be 36.45%. The standard deviation of MAR was found to be 24.7% and the coefficient of variation of 0.678; which higher than to 0.5 respectively. It indicated that there is a very high appreciable change of soil MAR after leaching experiment.

Additionally, the statistical findings showed that the Kelly ratio also ranges from 0.1799 to 1.521 and the average mean of KI was found to be 0.582. The standard deviation of KI after leaching experiment was found to be 0.37 and the coefficient of variation of 0.636 which is higher than 0.5. It means that there is a very high appreciable change of KI in the tested soil after leaching experiment. Finally, the research findings showed that the Soluble Sodium Percent of soil ranges from 27.98% to 71.71% with the average mean of SSP of 50.252% respectively. The standard deviation of SSP after leaching experiment was found to be 11.21% and the coefficient of variation (CV) of 0.223 which is less than to 0.5. It indicated that there is no appreciable change of soil SSP after leaching experiment.

Effect of saline water leachates on soil pH, EC, SAR, MAR, KR, and SSP by T-test of equality means

The T-test was performed to compare the equality of means of soil pH, EC, SAR, MAR, KR, and SSP after leaching experiment as prescribed in routine methodology presented in section 2 above, two parameters were used not only limited to Treated soil; which is soil that have received leachates to perform leaching experiment, but also to Control soil with is soil that never received any treatment during the experiment and their means were recorded respectively in data sheet. The DID (Difference-In-Difference) and t-test were used to compare the effect of leaching experiment on pH, EC, SAR, MAR, KR, and SSP of the soil after leaching and leachate seepage. The summary of results is shown in **Table 10**.

The t-test was performed through the difference in difference (DID) econometric models to test the significance factors after leaching. The tested parameters were pH, EC, SAR, MAR, KR and SSP of the soil. After running DID t-test,

Table 10. Effect of saline water leachates on soil pH, EC, SAR, MAR, KR, and SSP by T-test of equality means.

Variables	Control soil	Treated soil	Difference	S.E.	T-stat	P > |T|
pH	5.905	6.012	0.107	0.543	0.2	0.829
EC (μS/cm)	95.144	71.720	−23.425	16.368	−1.43	0.0924*
SAR	0.241	0.351	0.110	0.109	1.01	0.0112**
MAR (%)	38.485	46.980	8.495	11.098	0.77	0.281
KR	0.353	0.496	0.142	0.181	0.79	0.259
SSP (%)	36.717	49.753	13.035	5.586	2.33	0.0040**

Noted that *, ** and *** correspond to 10%, 5% and 1% significance levels; ppm: part per million and S.E: standard error.

the results from the T-test showed that the soil salinity (EC) content in μS/cm decreased by −23.425 μS/cm statistically significant after leaching experiment with p-value of $0.0924 < 0.1$ level of significance respectively. The study findings showed that, after t-test, there is statistical significance difference increase of 0.110 with ($p = 0.0112 < 0.05$). Finally, the t-test results showed SSP was statistically significance increased by 13.035% with $p = 0.004 < 0.05$ level of significance respectively. Unexpectedly, the results show that application of saline water in irrigation decreases the soil salinity and increases the levels of soil alkalinity and Na % in the soil horizons. The significant interaction between irrigation saline water and EC of the soil indicated inverse relationship and this shows the partial substitution of each other in affecting crop growth. These findings are coherent with the research conducted by [20] who found that there is negative effect of saline water on crop growth. Referring the research findings, saline water application in irrigation will cause the accumulation of SAR and Na% in the top soil layers. In some instance, the need of irrigation with saline and sodic waters has been raised have been impacted the change of Na%, SOM, SSSI and CEC within the soil. These issues will be handled over by application of soil amendments like gypsum and soil reclamation. Thus these findings are supported by the findings of [21] who find similar findings.

4. Conclusion and Recommendations

The experimental results indicated that intensive irrigation with saline water decreases soil texture, Soil Organic Matter and Soil Structural Stability Index (SSSI). It reduces also the soil bulk density and soil porosity which therefore affect soil aeration. For nutrients, except the increase of available of P, K^+, Mg^{2+}, S, CN ratio and Na, the successive irrigation of saline water decreases the soil macro and micro nutrients through deep water percolation and seepage. The study findings concluded that there is a significant indicated inverse relationship between irrigation saline water and EC of the soil and this shows the partial substitution of each other in affecting crop growth. It is concluded that saline water application in irrigation cause the accumulation of SAR and Na% in the top soil layers. In this regard, CV was found to be less appropriate for the experimentation. The study indicated that saline is an inefficient amendment for sandy soil with saline water irrigation. Leaching saline water on soil can have both positive and negative effects on soil properties, depending on various factors such as the initial soil conditions, the salinity of the water, and the leaching process itself. The study recommends further studies with similar topic with saline water irrigation, as it accentuated the alkalinity levels. By overall, leaching can be an effective tool to reclaim saline-affected soils, but it should be carefully managed to avoid potential negative impacts on soil properties and the environment. Local conditions and specific soil characteristics should be considered when implementing any soil leaching practices.

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Conflicts of Interest

The authors of this article declare that there is no conflict related to this work.

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