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Nutrient Dynamics in Soil Treated with Sewage Sludge and Irrigated with Desalinator Reject

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ABSTRACT

Sewage sludge is a residue whose composition varies depending on the origin and the treatment process used, being, therefore, a material essentially rich in stable organic matter, macronutrients and a wide range of micronutrients. Much research on the use of sewage sludge in agricultural soil is being carried out to evaluate its effect on the physical, chemical and biological properties of the soil. An experiment was installed under laboratory conditions using percolation tubes in order to evaluate the effect of the built-in and surface sewage sludge on the physic-chemical characteristics of the soil irrigated with desalinator reject. The experimental design adopted was completely randomized, with three replications, totaling nine plots. The experiment lasted 60 days; the leachates were collected at 15-day intervals and analyzed physically-chemically. After statistical analysis, it was noticed that after 15 days of soil contact with sewage sludge (SS), a greater percolation of the studied elements was noticed, indicating less adsorption in the soil, with the time of up to 30 days being the most favorable to adsorption of minerals in silt-free soil in the presence of incorporated SS, corroborated by pH and electrical conductivity.

Keywords: *Leaching, biosolid, saline effluent, soil.*

INTRODUCTION

Soil is essential for the development of human life, since it is the soil that supports plants, on which humanity depends directly or indirectly. In addition, the soil plays important roles in the relationships and interactions existing in the biosphere. The use of this natural resource must be guided by practices aimed at minimizing or even preventing its degradation, and consequently maintain environmental quality [1, 2].

The process of treating sewage to return water to water bodies generates a residue called sewage sludge which is a waste of an organic character and which contains levels of organic and inorganic components. Sewage sludge is a residue that has great potential for agricultural and forest use, both as a condition for the physical, chemical and biological properties of the soil, and as a source of nutrients for cultivated plants, in view of its chemical composition. Sewage sludge, after treatment for agricultural use, can also be called biosolid [3, 4].

According to [5], depending on the origin and the process used to obtain it, sewage sludge has a very variable composition, being a material rich in organic matter (40 to 60%), nitrogen and some micronutrients. A typical sewage sludge contains 40% organic matter, 4% nitrogen, 2% phosphorus and 0.4% potassium.

The process used for water desalination in the Northeast is based on reverse osmosis. Such a process implies the generation of a reject, a wastewater from the process, with high ionic concentration. The theoretical yield is 75%, that is, about 25% of the raw water is transformed into saline reject. This extremely salt-rich reject is deposited in decanting ponds or placed in the open air, without major concerns, constituting a real environmental challenge to be solved, since it directly contributes to the generation of other problems, such as the increase in the saline area and consequent agricultural infertility [6, 7].

In this way, the great challenge of using the water treatment system is in the disposal or reuse of wastewater, in order to avoid negative impacts on the environment and the communities that benefit from this technology [8, 9].

Therefore, the best option to dispose of the desalinator reject must meet, among other factors, local availability (land, compatibility of receiving waters and distance), regional availability (geology, state laws, geography and climate), the volume of concentration, the costs involved, public opinion and the permissibility [10].

Thus, an experiment was set up to evaluate the influence of sewage sludge and irrigation with desalinator reject on the physicochemical characteristics of a frank silty soil.

MATERIALS AND METHODS

The experiment was installed at the Analytical Chemistry Laboratory, 8th floor of block D of the Science and Technology Center of Catholic University of Pernambuco, Recife, Pernambuco, Brazil.

The soil used was collected at the São Bento do Una Experimental Station of the Agronomic Institute of Pernambuco (IPA) in the Laboratory of Soil Fertility of the IPA, where a chemical analysis was carried out, determining pH (H_2O) = 7.8; P = 350 mg/dm³; Ca^{2+} = 16 cmolc/dm³; Mg^{2+} = 3.9 cmolc/dm³; Na^{+} = 3 cmolc/dm³; K^{+} = 0.7 cmolc/dm³ and Al^{3+} = 0 cmolc/dm³. The physical characteristics of the soil were Dap = 1.29 g/cm³; Dr = 2.62 g/cm³; Coarse sand = 7%; Sand = 21%; Silt = 56%; Flocculation = 100%; Clay = 19%; Texture = silt frank; Residual humidity = 1.7%.

The sewage sludge was supplied by the Curado Sewage Treatment Station, located in the city of Recife, PE, and analyzed at the Plant, Ration and Water Analysis Laboratory (LAPRA) at IPA, presenting the following characteristics: pH (H_2O) = 7.5; Ca^{2+} = 168.02%; Mg^{2+} = 6.38%; Na^{+} = 3.66%; K^{+} = 1.49%; Cl^{-} = 600.66%; N = 1.38%; C = 92.00% and ratio C/N = 66.67%.

The reject for irrigation was obtained from the desalinator located in the municipality of Riacho das Almas, Pernambuco, Brazil. The physicochemical analysis was performed at the IPA Plant, Ration and Water Analysis Laboratory (LAPRA) with the following characteristics: electrical conductivity = 11.541µS/cm at 25ºC; Ca^{2+} = 403mg/L; Mg^{2+} = 393.09 mg/L; Na^{+} = 200mg/L and K^{+} = 40mg/L; RAS = 23.67; pH = 7.9; Classification for irrigation = C4S4 (very high salinity water and high sodium concentration).

For the installation of the experiment, nine PVC tubes with 25cm height and 9.8cm internal diameter were used, presenting an opening at the base connected to a flexible hose of 0.7cm in diameter that allowed the percolating liquid to pass through the soil to the collector container.

The tubes were filled with 1.5 kg of soil, enough to obtain a 20 cm high column. Then 300g of the sewage sludge was applied to the surface and incorporated into the soil, with irrigation with the reject twice a week.

The percolated water in each tube was collected in polyethylene flasks, at intervals of 15 days, up to 60 days, being determined pH (potentiometry), EC (conductivity), Na^{+} (flame emission spectrophotometry), Ca^{2+} and Mg^{2+} (titrimetry of complexation) and Cl^{-} (precipitation titrimetry - Mohr method), for later statistical analysis, using Minitab 19 software.

RESULTS AND DISCUSSION

The results obtained for pH, electrical conductivity, sodium, calcium, magnesium and chloride are shown in Figs. 1 to 6, in Tables 1 to 6, as well as in their respective equations.

pH

According to the pH results contained in Table 1 and Fig.1, it can be seen that after 15 days of soil contact with the sewage sludge (SS), at the surface and incorporated, as well as the control, the percolate pH increased to 9 in relation to the initial values of soil (7.8), SS (7.5) and desalination waste (7.9). Then, there was a decrease to 8 in the other contact times (30, 45 and 60 days), remaining with alkaline characteristics.

Table1. *pH values in treatments and contact time used*

	15 days	30 days	45 days	60 days
WITNESS	9.12	8.26	8.22	8.36
SS INCORPORATED	9.16	8.37	8.34	8.32
SS SURFACE	9.13	8.49	8.5	8.41

Where: SS = sewage sludge.

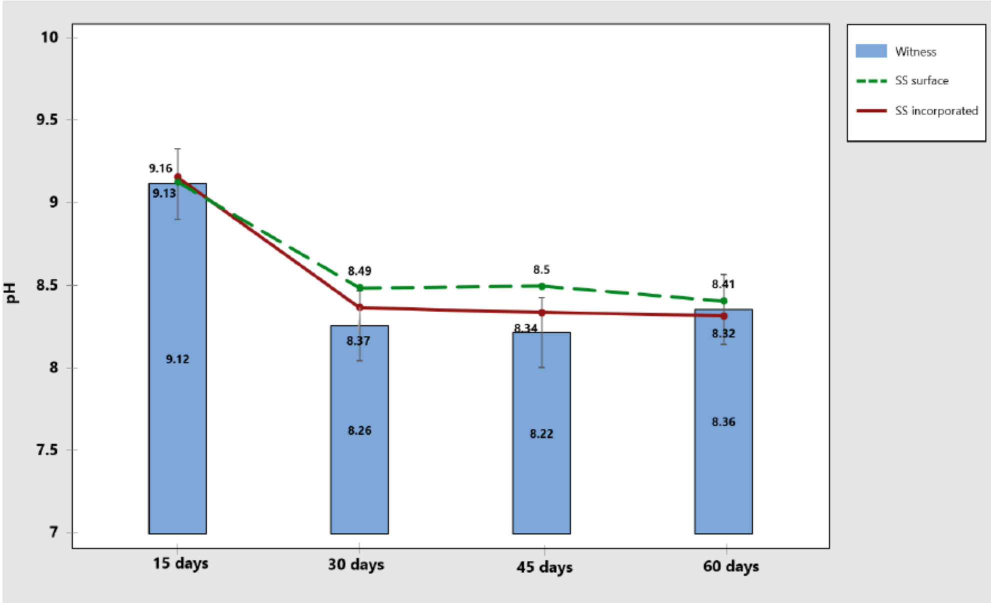

Fig.1. pH results in treatments and contact time used

The witness, SS surface and SS incorporated pH Equations and determination coefficients are:

Witness

Y = 9.07 – 0.232*t (R^2 = 0.4987)

SS surface

Y = 9.17 – 0.215*t (R^2 = 0.6902)

SS incorporated

Y = 9.185 – 0.255*t (R^2 = 0.6483)

The fertilization of the soil with sewage sludge promotes the reduction of pH as a result of the process of formation of organic acids and ammoniacal nitrogen nitrification reactions present in the sludge [11]. On the other hand, [12] report an increase in soil pH with the application of sludge, since in the stabilization process of this sludge is added virgin lime, with alkaline reaction. However, these authors did not find variation in soil pH with the application of solarized sewage sludge, composted and vermicomposted in the fertilization of sunflower.

The study by [13], in the evaluation of the chemical characteristics of soil cultivated with soybean, irrigated with swine wastewater, showed that for the pH there were no significant differences in the adopted treatments, which presented high acidity, differentiating from this study that presented basic characteristics.

According to [14], the pH of the soil solution decreases with the increase in the applied dose of nutrients; in addition, the sources of nitrogen and phosphorus have an acid reaction and, therefore, the higher the dose applied, the greater the acidifying effect on the soil solution. Also, when the pH values are high, they favor the nitrification process, as the microorganisms responsible for nitrification are sensitive to acidity and require high pH values for maximum activity [15].

Electrical Conductivity

From Table 2, Fig. 2 and corresponding Equations, it can be seen that the electrical conductivity of the percolate at 15 days of contact of the soil with the sewage sludge on the surface (37.65µS/cm, R^2 = 0.897) was greater than the SS incorporated in the soil (32.84µS/cm, R^2 = 0.721), indicating less adsorption of chemical elements in the frank silty soil used in the experiment, even though the values are lower than the one presented by the witness (44.20µS/cm, R^2 = 0.5759).

It is also noted that, after 30 days, the electrical conductivity of the percolate shows a decrease in values until the experimental 60 days, mainly with SS on the soil surface, indicating greater adsorption of salts on the soil.

Table 2. Electrical conductivity values (µS / cm) in treatments and contact time used

	15 days	30 days	45 days	60 days
WITNESS	44.2	12.5	17.77	12.84
SS INCORPORATED	32.84	26.07	28.12	14.77
SS SURFACE	37.65	23.93	23.53	13.84

Where: SS = sewage sludge.

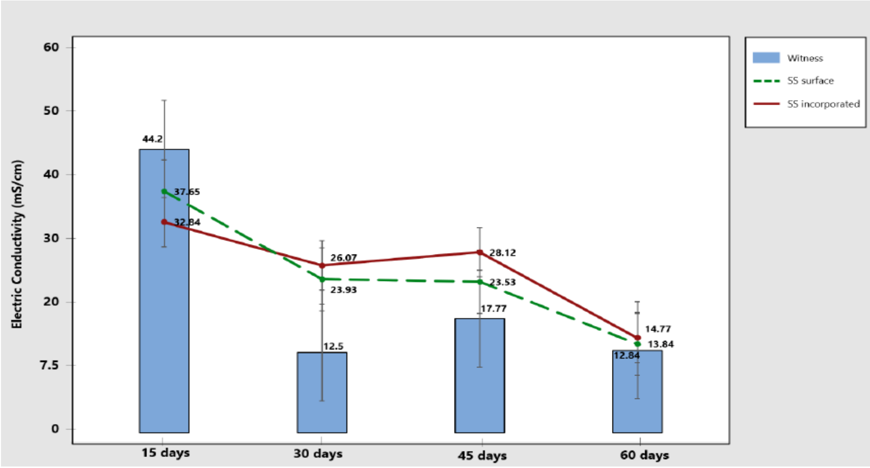

Fig. 2. Results of electrical conductivity (μS / cm) in treatments and contact time used

The witness, SS surface and SS incorporated EC Equations and determination coefficients are:

Witness

Y = 44.03 – 8.881*t (R^2 = 0.5759)

SS surface

Y = 42.69 – 7.183*t (R^2 = 0.8970)

SS incorporated

Y = 38.49 – 5.216*t (R^2 = 0.7721)

Contrary to the study by [16], on the behavior of salinity and pH of soil under melon cultivation irrigated with saline water, it was observed that, in the first weeks, salinity was low in the entire soil profile, with an average EC of 1.01 dS/m, which increased during the first crop cycle. However, the same study reinforces that successive irrigations can increase the concentration of salts accumulated in the soil profile.

According to [14], the values of electrical conductivity of the soil solution increase according to the increase in the applied dose of organic matter. Furthermore, the greater the depth of the soil, the greater the electrical conductivity.

Sodium

It can be seen from Table 3, Fig. 3 and corresponding Equations that sodium showed a higher value in percolate at 15 days of collection, in the SS surface (6350.00mg/L, R^2 = 0.8061) when compared to the SS incorporated (5350.00mg/L, R^2 = 0.8675) and lower than the witness (6480.00mg/L, R^2 = 0.6808), indicating a lower sodium adsorption in the soil.

The availability of this nutrient is strictly related to chemical properties such as sorption, desorption and precipitation reactions of inorganic ions that occur in soils [17].

Table 3. Sodium values (m g / L) in treatments and contact time used

	15 days	30 days	45 days	60 days
Witness	6480.00	2946.67	2320.00	2510.00
Ss Incorporated	5350.00	3773.33	3840.00	2766.67
Ss Surface	6350.00	3846.67	2663.30	2773.33

Where: SS = sewage sludge.

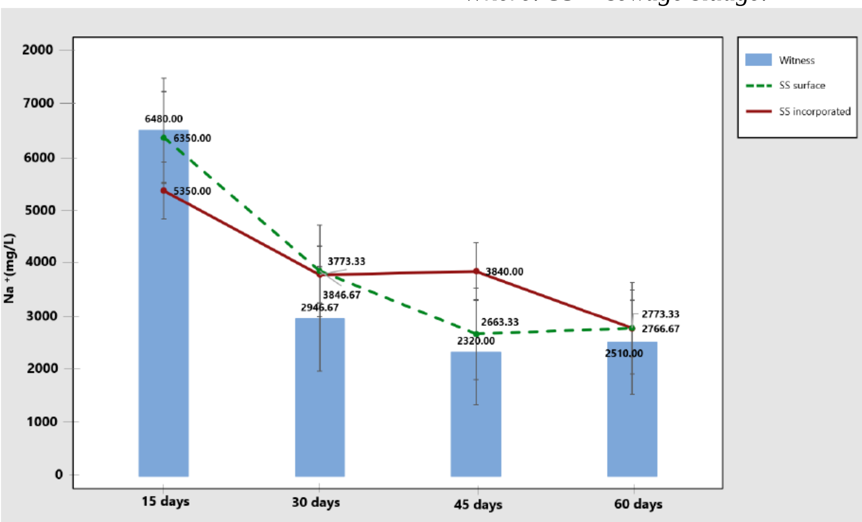

Fig. 3. Sodium results (mg / L) in treatments and contact time used

The Witness, SS surface and SS incorporated sodium Equations and determination coefficients, are:

Witness

$Y = 6689.3 - 1253.7*t$ ($R^2 = 0.6808$)

SS surface

$Y = 6886.7 - 1191.3*t$ ($R^2 = 0.8061$)

SS incorporated

$Y = 5853.8 - 766.33*t$ ($R^2 = 0.8675$)

The experiment by [18] compares studies that show that the application of swine wastewater and the application of treated sanitary sewage, through the surface drip irrigation system, provided an accumulation of exchangeable sodium reaching 23.46mg / L in soil cultivated with forage grasses. The study also shows that the tested treatments favored the sodium leaching from the superficial layers to the deeper ones, thus having a higher exchangeable sodium concentration in the evaluated profiles, except in the control sample.

According to the diagnosis made by [19], sodium ions were retained in soils with greater intensity in relation to other ions, for example, calcium. [20], reports that sodium ion concentrations may vary according to the treatment used. In addition, soil texture has an influence on the sodium leaching process; thus, clayey soils have less sodium retention; sandy soils have higher chemical element retention.

The effect of excess salts impairs the vegetative and productive behavior of plants by the action of direct effects on the osmotic potential and potentially toxic ions in the soil solution [21].

Calcium

In Table 4, Fig. 4 and corresponding Equations are the results of the determination of calcium in the percolate. It is noted that at 15 days there is no presence of this element indicating greater adsorption of calcium in the soil, favored by the increase in pH, regardless of the treatment used.

Still, at 30 days there was a greater presence of calcium on the SS surface (3352.57mg/L, $R^2 = 0.0242$) than on the SS incorporated (916.50mg/L, $R^2 = 0.0667$), who returns to zero calcium at 45 and 60 days.

Therefore, there is an indication that the reactions with soil correction or organic matter favor the elimination of toxic elements, such as aluminum and manganese, when they are incorporated into the soil for 15 to 45 days.

In the work developed by [13], the results of calcium and magnesium did not show statistically significant mobility, in the soil profile with the application of wastewater confirming, the results found by other authors who observed that the soil texture influenced the retention of cations potassium, sodium, calcium and magnesium in clayey soil, compared to sandy and frank sandy soil.

In the study of [22], calcium tests decreased, according to the leaching time, corroborating with this behavior experiment that the SS recorded after 45 days, which were not tested in its percolate. The decrease in the concentration of calcium in the sample may be due to the precipitation of its salts at the bottom of the leaching column.

Table 4. Calcium values (mg / L) in treatments and contact time used

	15 days	30 days	45 days	60 days
Witness	0.00	0.00	445.15	445.15
Ss Incorporated	0.00	916.5	0.00	0.00
Ss Surface	0.00	3352.57	1256.91	1256.91

Where: SS = sewage sludge.

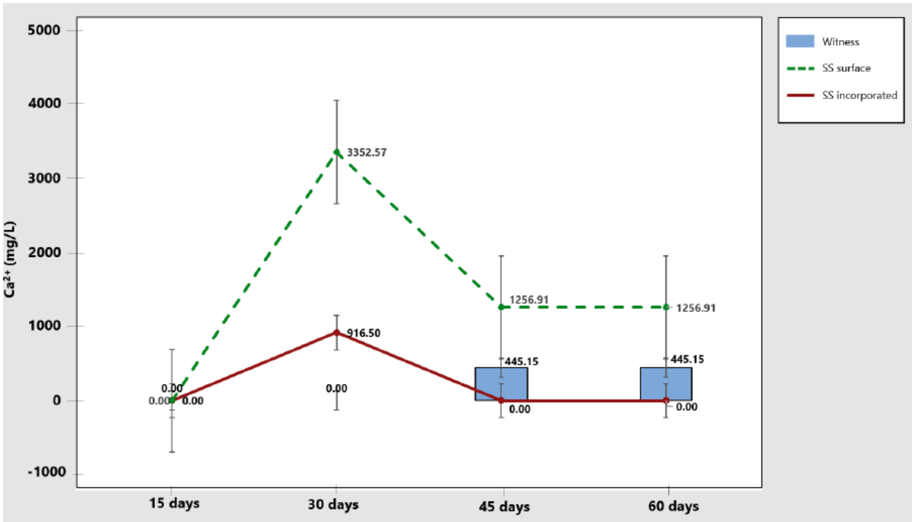

Fig. 4. Calcium results (mg / L) in treatments and contact time used

The Witness, SS surface and SS incorporated calcium Equations and determination coefficients are:

Witness

Y = 22.85 + 178.06*t (R^2 = 0.8071)

SS surface

Y = 1047.8 + 167.51*t (R^2 = 0.0242)

SS incorporated

Y = 458.25 – 9165*t (R^2 = 0.0667)

When assessing the calcium retardation factor in soil percolates irrigated with treated domestic and swine wastewater, [19] observed that the lower the speed of advance of the solution in the soil column, the greater the contact time between the ions and the soil colloids, promoting a greater opportunity for solute retention, causing an increase in the delay factor.

Magnesium

According to Table 5, Fig. 5 and corresponding Equations, at 15 days of soil contact with SS incorporated (681.36mg/L, R^2 = 0.3675), it shows lower value in percolate for magnesium, indicating greater adsorption of the element in the soil, compared to SS surface (1252.97mg/L, R^2 = 0.6223) and witness (6476.74mg/L, R^2 = 0.7655).

If the option were to discard the sewage sludge on the soil surface, contact would be required for 30 days (340.42mg / L) or 45 days (314.23mg / L), so that the magnesium remains more adsorbed to the soil.

The magnesium concentration in the study by [14], which was supplied by the liming process, showed an increasing trend of concentration in the leachate, due to the greater acidification.

On the other hand, [23], in a study on fertilization of *Jatropha curcas* with sewage sludge, found a reduction in magnesium levels in the soil, attributing this fact to the greater growth and absorption of this element by the plant.

When analyzing the magnesium concentrations in his study, [22] indicated the decrease in magnesium concentration in the soil during the experiment time.

Table 5. Magnesium values (mg / L) in treatments and contact time used

	15 days	30 days	45 days	60 days
Witness	6476.74	2212.68	1021.24	1021.24
Ss Incorporated	681.36	2487.63	2055.57	2055.57
Ss Surface	1252.97	340.42	314.23	314.23

Where: SS = sewage sludge.

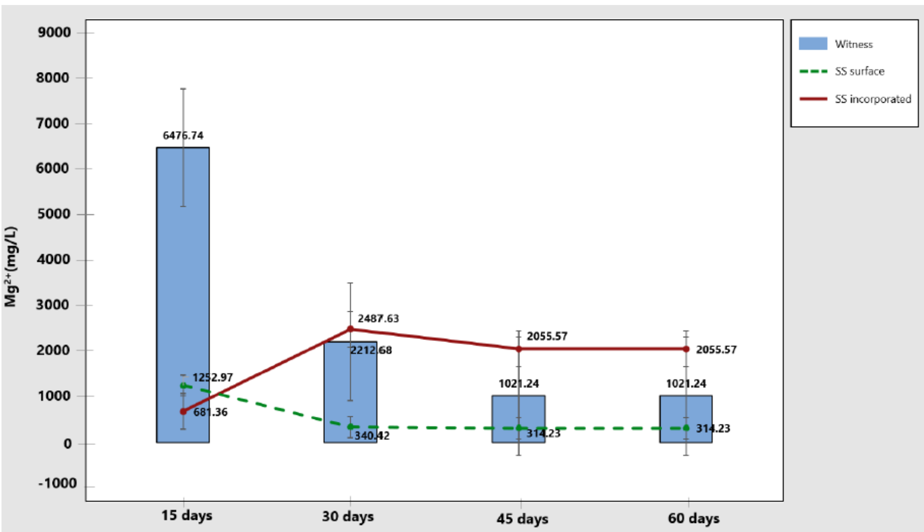

Fig. 5. Magnesium results (mg / L) in treatments and contact time used

The Witness, LE surface and LE incorporated magnesium Equations and determination coefficients are:

Witness

Y = 7072.5 – 1755.8*t (R^2 = 0.7655)

SS surface

Y = 1266.1 – 284.24*t (R^2 = 0.6223)

SS incorporated

Y = 897.39 – 369.06*t (R^2 = 0.3675)

To [13], the magnesium behavior in the leaching test did not show significant values, being little affected with the application of wastewater, contrary to the data collected in the present study.

Finally, [15] reinforce that sodium, together with magnesium, calcium and potassium; constitute the exchangeable cations in the soil. The higher the percentage of sodium between the bases, the lower the saturation of the soil exchange sites occupied by calcium, magnesium and potassium.

Chloride

For the chloride content in the percolate, it can be seen from Table 6, Fig. 6 and corresponding Equations, that the values obtained after the contact times (15; 30; 45 and 60 days) between the sewage sludge, on the surface or incorporated, and the soil, including the witness, were higher than indicated by Decree 2914/11 of the Ministry of Health, which recommends that the chloride concentration in the leachate not exceed 250mg / L.

Even so, at 15 days the incorporated LE showed the lowest value for chloride in the percolate (3357.00mg/L, R^2 = 0.01533), compared to other treatments and contact times, indicating the possibility of adsorption of this element in the soil used.

[24] announced that soils composed of kaolinitic minerals have a greater ease of adsorption than lateritic soils, justified by the cation exchange capacity and the dominance of negative charges in the kaolinitic material, an idea also reinforced by [25].

Table 6. Chloride values (mg / L) in treatments and contact time used

	15 days	30 days	45 days	60 days
WITNESS	5486.00	5172.40	5989.90	5989.90
SS INCORPORATED	3357.00	10345.00	7274.70	7274.70
SS SURFACE	4521.60	9627.20	5873.10	5873.10

Where: SS = sewage sludge.

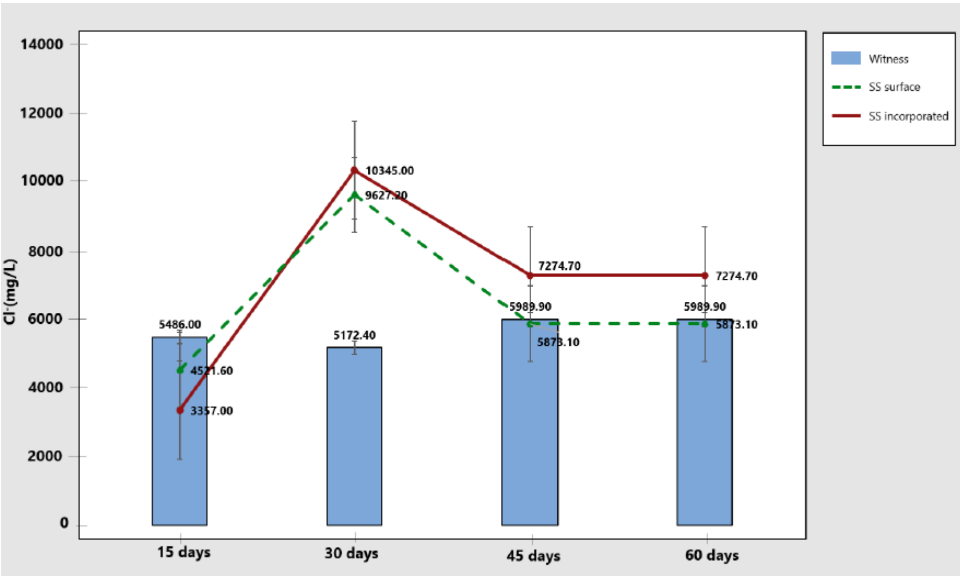

Fig. 6. Chloride results (mg / L) in treatments and contact time used

The Witness, LE surface and LE incorporated chloride Equations and determination coefficients are:

Witness

Y = 5077.2 + 232.92*t (R^2 = 0.5585)

SS surface

Y = 6398.7 + 30.04*t (R^2 = 0.003)

SS incorporated

Y = 4892.2 + 868.28*t (R^2 = 0.1533)

In the work of [26], it is possible to observe that chloride showed high mobility and low sorption in sandy soil columns, possibly from solute advancement; as well, it presented a greater factor of retardation of mobility in clayey to silty soils, attributing the adsorption by the presence of kaolinite and the oxides of iron and aluminum or by the exchange of hydroxyls present in the soil surface, which occurred in this study where the soil used has frank silty texture.

CONCLUSION

According to the results obtained, it can be concluded that the raw materials used in the experiment (soil; sewage sludge; desalinator reject) showed alkaline pH. The percolate pH at 15 days experimental increased to the range of 9 falling to 8 in the other days and time. At 15 days of contact, the electrical conductivity of the percolate with SS surface (37.65µS/cm) was higher than with the SS incorporated (32.84µS/cm) and both lower than the witness (44.20µS/cm). The percolate showed higher value for sodium at 15 days of contact of the frank silty soil with SS surface (6350.00 mg/L) in relation to the SS incorporated (5350.00mg/L) and lower than the control (6480.00mg/L). For percolated calcium, at 15 days of soil contact with sewage sludge, there is no presence of this element, indicating adsorption of calcium in the soil. At 30 days, calcium is present in the SS surface (3352.57mg/L), in the SS incorporated (916.50mg/L), indicating desorption of calcium from the soil. At 45 and 60 days, there is again adsorption of calcium in the soil. The leachate from the SS incorporated treatment showed lower value for magnesium (681.36 mg/L), at 15 days of soil contact and sewage sludge. Chloride showed high values in percolate , higher than recommended by the Ministry of Health (250.00 mg/L). At 15 days, the SS incorporated showed the lowest value (3357.00 mg/L) compared to the other treatments and contact times. There is an indication that the sewage sludge positively influenced the chemical attributes studied in the frank silty soil (pH, CE, Na^+, Ca^{2+}, Mg^{2+} and Cl^-). Soon after 15 days of soil contact with sewage sludge, a greater percolation of the studied elements was noticed, indicating less adsorption in the soil, the time of up to 30 days being the most favorable to the adsorption of minerals frank silty soil in the presence of SS incorporated.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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