Role of gypsum and intermittent leaching in reclaiming saline-sodic soils in El-Qantara Gharb region, Ismailia, Egypt

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Abstract: Salt-affected soils have undesirable properties for crop production. However, these problems can be treated and regained for cultivation. A field experiment was conducted to evaluate the impact of different rates of gypsum application on soil salinity soil reaction (pH) and sodicity of the saline-sodic soil under intermittent leaching conditions. The experiment was carried out over two years on a clayey saline-sodic soil at El-Qantara Gharb region, Ismailia Governorate, Egypt. The treatments were distributed in four randomized blocks of 20 x 15 m and the soil was subjected to intermittent leaching for fifth leachates, and evaluated soil salinity, soil reaction (pH) and soil sodicity before and after gypsum application and leaching. Gypsum was applied at rates of zero, 50, 75 and 100% of the predetermined gypsum requirements (50 t ha-1) (0.0, 25. 37.5 and 50 t ha-1) respectively. Five intermittent leaching cycles were performed with proper drainage. Generally, gypsum addition at all rates pronouncedly improved soil salinity soil reaction (pH) and soil sodicity of the saline-sodic soil compared to the control treatment (without gypsum addition). Where the best values were recorded due to the gypsum addition rate of 100% followed by 50% and 25%, respectively for soil characteristics. Also, the results confirm that agricultural gypsum application in Egypt is beneficial for improving saline-sodic soils due to its high content of calcium.

Keywords: Agricultural gypsum, Saline-sodic soils, Intermittent leaching, Soil reclamation, El-Qantara Gharb region.

INTRODUCTION

Salt-affected soils occur all over the world mostly under all climatic conditions, especially in arid and semi-arid zones. More than 830 million hectares of agricultural land in worldwide are salt-affected soils (FAO, 2021), and those area accounts for about 6% of the world's total land area, In Egypt salt-affected soils cover about 0.9 M ha, they represent about 35 % of cultivated soil, located in the northern-central part of the Nile Delta and on its eastern and western sides (Central Agency for Public Mobilization and Statistics (CAPMAS, 2018)). However, 25% of the soils in upper Egypt, 20% of those in the southern Delta and Middle Egypt, and 55% of those in the northern Delta have soils that are influenced by salt (Mohamed, 2017). Improving salt-affected soils requires the removal of excess salts to a desired level in the root zone. In saline-sodic and sodic soils, the excess of Na^+ content relative to the other cations is the main negative influence on soil productivity (Eynard *et al.* 2005), this means that sodium must be removed by leaching and adding a source of calcium to replace of sodium exchangeable. The most popular chemical amendment is agricultural gypsum ($CaSO_4\ 2H_2O$) because gypsum is available, low cost, easy of handling and improves drainage, and can reduce soil salinity and sodicity (Day *et al*., 2019). In this context, the objective of this study is to evaluate the effect of the application of different rates of agricultural gypsum with intermittent leaching on soil chemical properties in El-Qantara Gharb region.

MATERIALS AND METHODS

To achieve the goal of this investigation, a field experiment was conducted in western El-Qantara, Ismailia, Egypt. The objective of this research is to evaluate the effect of the application of different rates of agricultural gypsum with intermittent leaching on some chemical properties of one of the degraded soils (saline-sodic soils) in Egypt.

The investigated soil: The soil used in the current investigation was a clay saline sodic. The soil was analyzed before improvement processes according to Dewis and Fertias (1970), Tables 1 and 2 show some chemical and physical characteristics. The gypsum used in the investigation was a natural agricultural gypsum with a minimum purity of 83.72%. It was provided by the Egyptian Division of Land Improvement.

Soil preparation: Before starting the improvement process, the field was prepared by plowing, leveling the soil, and creating appropriate drainage. Afterward, the soil was divided into four plots, each plot was 20 m long and 15 m wide (area = 300 m^2). Irrigation canals are also prepared to convey leaching water from the nearest irrigation canal, which conveys water from a port-said canal about 2 km away.

Experimental design: The treatments were arranged on a split plot in complete randomized block design in three replicates. The addition of gypsum was made as 0, 50, 75 and 100% of gypsum requirements (GR = 50 t ha^{-1}). Intermittent leaching was used in the current investigation. Five leaching cycles were conducted for each treatment. Before starting leaching, a 20 cm depth of water was added to each plot to bring the soil to saturation. The water depth was carefully added, the time needed to operate the water pump was calculated by knowing the plot area (300 m^2) and the water flow rate from the pump (pump discharge rate). Soil samples were collected at end of each leaching cycle to perform some chemical and physical soil analyses.

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Table (1): Some chemical properties of investigated soils

Soil chemical properties		Value
pH		8.55
EC, dS m^{-1}		16.33
CaCO3 %		7.5
OM%		0.80
SAR		24.7
ESP%		37.9
Soluble cations (mmol$_c$ L^{-1})	**Ca^{++}**	17.5
	mg^{++}	26.5
	Na^+	117.8
	K^+	4.0
Soluble anions (mmol$_c$L^{-1})	**HCO_3^-**	7.0
	Cl^-	96.0
	SO_4	62.8
Exchangeable Cations (cmol$_c$ kg^{-1})	**Ca^{++}**	6.6
	mg^{++}	10.7
	Na^+	12.8
	K^+	0.24
CEC (cmol$_c$kg^1)		30.4

Table (2): Some physical properties of investigated soils

Soil physical properties		Value
Particle Size Distribution	**Sand %**	39.5
	Silt %	19.5
	Clay %	41.0
Texture		Clay
Bulk density Mg m^{-3}		1.34
Saturation percentage (SP)%		48.2
Total porosity %		54.8

Data recorded: Air-dried soil samples were crushed, sieved with 2 mm, and stored in order to perform the following: 1- Physical analyzes of the soil such as soil bulk density (Mg cm- ^{3}) was determined using core method, klute and Dirksen (1986) and total soil porosity (p %) was calculated using both real and bulk density values. 2- Chemical analysis such as soil pH was determined in (1:2.5) soil water suspensions, while Electrical conductivity (dS m^{-1}) was determined in the saturated soil paste extract according to Jackson (1973). Organic matter content (%) was determined according to (Hesse, 1971). Total carbonate was determined as calcium carbonate using Collin`s calcimeter (Piper, 1947). Soluble cations and anions were determined in saturated soil paste extract according to Jackson (1973). sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) were determined by Olsen *et al*., 1982. Gypsum requirements of soil were calculated by the calculation methods recommended by Ashworth, (1999) for high saline sodic soils. The selected soil physical properties were conducted by the methods described by (Klute, and Albert. 1986).

Statistical Analysis: All the obtained data from the two experiments were subjected to the analysis of variance (ANOVA) using CoStat (ver. 6.311) software **(**Cohort Program, 1990). The comparison between means at ($p < 0.05$) was made by the least significant difference test (LSD).

RESULTS AND DISCUSSION

Soil salinity (EC) : By reading the data listed in Table (3) which shows effect of different gypsum applications and the number of leachates on EC (EC dS m^{-1}, the data declare a noticeable reduction in soil salinity as a result of gypsum applied for the selected soil in compare with untreated soil (control). Fig. (1) illustrates that there is a very sharp decrease in EC values for all treatments, particularly at the beginning of the leaching process (after the first leachate) When compared with the value of the decrease between the following leaching periods, where greater portions of salts were removed after the first leachate (L1). In this regard, the rate of decrease in the value of EC after the first leachate only in all treatments ranged between 19.53% to 40.6% from the initial EC (16.33 dS m^{-1}), while at the end of the leaching processes completely the rate of decrease in soil EC ranged between 43.96% to 69.68% for all treatments. From our data, we noted that whether the soil plots were treated with gypsum or not, there was a considerable decrease in EC after the first leachate, that agreement with Abd El-Fattah, 2014 who reasoned that by the amount of applied water to the first leachate was capable of removing the majority of the readily soluble salts (such as NaCl and Na_2SO_4) and mobile ions such as chloride and sodium. After that, the decrease in EC becomes a qualitative decrease, especially in the presence of gypsum, where the interaction zone is supplied with calcium and sulfate ions, thus working to expel more of the exchangeable sodium to the distant layers of the soil. From the results in Table 3, the soil-EC of the saturated paste extract showed a significant ($p \leq 0.05$) decrease between the different gypsum treatments among them, which the decline in EC was as follows: T4 > T3 > T2 > T1. So, it is clear, that the maximum reduction in EC in the soil plots at the end of the leaching processes was obtained with the application of gypsum with a rate of 50 t ha^{-1} (T4) which was reduced by 69.7% (i.e. from initial EC 16.33 dS m^{-1} to 4.95 dS m^{-1}). Also, EC was reduced by 66.6 % (i.e. from initial EC 16.33 dS m^{-1} to 5.45 dS m^{-1}) and reduced by 61.2 % (i.e. from initial EC 16.33 dS m^{-1} to 6.33 dS m^{-1}) with the rates 37.5 t ha^{-1} (T3) and 25 t ha^{-1} (T2) respectively. However, EC is significantly affected by leaching with gypsum application as compared to leaching only. These results were in harmony with Deshesh, 2021 who indicated that it significantly reduced soil EC with gypsum application which allows a continuous supply of Ca^{2+}, this cation led to replacing the exchangeable Na^+ from the soil complex and to the formation of new stable aggregates.

Table (3): Effect of different gypsum applications and the number of leachates on EC (dS m^{-1})

Treatments (T)	Number of leachates (L)					Mean
	L 1	L 2	L 3	L 4	L 5	
T 1	13.41	12.25	11.33	9.70	9.15	**11.12**
T 2	10.28	8.21	7.85	7.24	6.33	**7.98**
T 3	10.21	8.08	7.65	6.84	5.45	**7.65**
T 4	9.70	8.00	7.50	6.16	4.95	**7.26**
Mean	10.83	9.14	8.58	7.49	6.47	
$LSD_{0.05}$	**(T) = 0.33, (L) = 0.37 and (T x L) ^{ns}**					
Initial $_{EC}$						**16.33**

T1, T2, T3 and T4 0.0, 25, 37.5 and 50 t ha^{-1} respectively

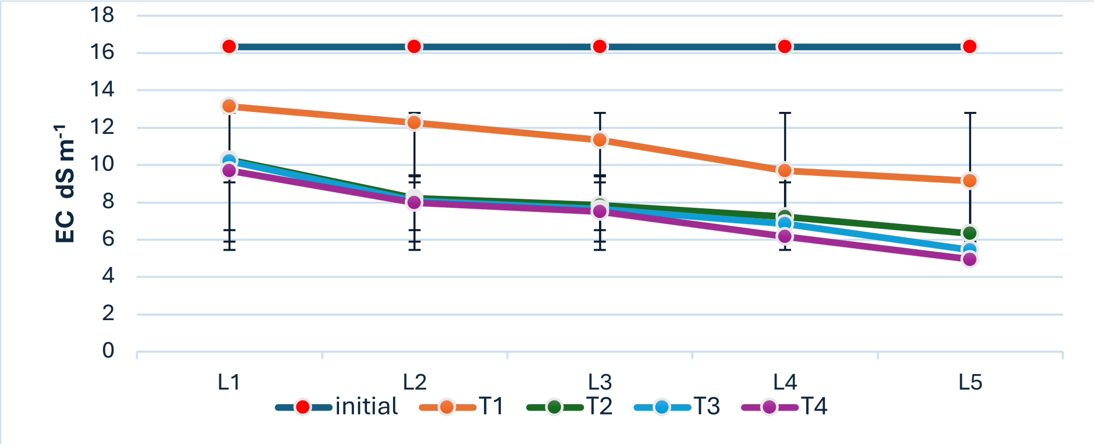

Fig. (1): Effect of different gypsum applications and the number of leachates on EC (dS m^{-1})

Soil reaction (pH): Table (4) and Fig (2) summarize the impact of gypsum applied at different rates before and during the leaching stage (five leachates) on the soil pH. Results showed that the addition of any rate of gypsum had a significant effect ($p \leq 0.05$) in decreasing pH, since the mean pH values ranged between 8.27 to 8.45 at the end of the leaching process in comparison with initial soil pH (8.55). The minimum decrease in pH value was recorded with non-application gypsum (T_1). This slight decrease in pH could be attributed to the buffering capacity of the soil. Moreover. the (GR100%) treatment was more effective in decreasing soil pH, compared to other treatments and control. that decrease in soil pH could be discussed by the calcium ions reacting with soil-bicarbonate to precipitate calcium carbonate (CaCO3) and release protons (H^+) in soil solution which neutralizes (OH^-) ions and decreases the soil pH **(**Rasouli *et al*., 2013). Also, the enhanced effect of gypsum in the decreased soil pH was probably due to a combination of more than one factor, gypsum applied activity coefficient of calcium and sulfate as a result of increased ionic strength of the solution and the formation of the sodium sulfate ion pair (Pintro *et al*., 1998). Aside from this, the decrease in soil-pH may be due to a decrease in Na^+ concentration as a fraction of the cations, this decrease may be due to the removal of exchangeable sodium from the soil which is replaced by calcium released from the gypsum dissolution. In addition, CO_2 must have evolved in large quantities during the leaching process, some of which would become soluble in soil solution giving carbonic acid (Abdel-Fattah, 2012). Moreover, the SO_4 ions of gypsum probably have contributed towards lowering the pH. (Khattak *et al*., 2007). From our study and given data presented in table (4) and Fig (2), the effect of the number of leaching cycles is evident on the pH values, the greater the number of leachates, the greater the decrease in the values of pH, especially in the presence of gypsum, where the efficiency of gypsum increases by increasing the amount of leaching water added to the experimental plots, this is due to the low solubility of gypsum (2.0 – 2.5 g L^{-1}), which requires addition large amount of leaching water to give the opportunity to dissolve larger amount of the applied gypsum, hence, releases more amounts of Ca^{2+} and $SO_4^{=}$ and eject quantities from exchangeable Na^+ which dominant in the soil, with emission of more hydrogen protons in soil solution, which reflects on neutralization of hydroxide ions, so in the end occurs decreasing in soil pH, that harmony with Khattak *et al*. (2007) who found that, the enhanced effect of gypsum expected when more amount of leaching water are added with provision of good drainage allowing the salts from the soil profile.

Table (4): Effect of different gypsum application and number of leachates on (pH)

Treatments (T)	Number of leachates (L) L 1	L 2	L 3	L 4	L 5	Mean
T 1	8.49	8.46	8.45	8.43	8.43	**8.45**
T 2	8.44	8.43	8.40	8.36	8.28	**8.38**
T 3	8.43	8.42	8.39	8.34	8. 22	**8.36**
T 4	8.42	8.38	8.35	8.21	8.00	**8.27**
Mean	8.45	8.45	8.40	8.33	8.23	
LSD0.05	**(T) = 0. 045, (L) = 0.051 and (T x L) = 0.10**					
Initial pH						**8.55**

T1, T2, T3 and T4 0,0, 25 ,37.5 and 50 t ha 1 respectively

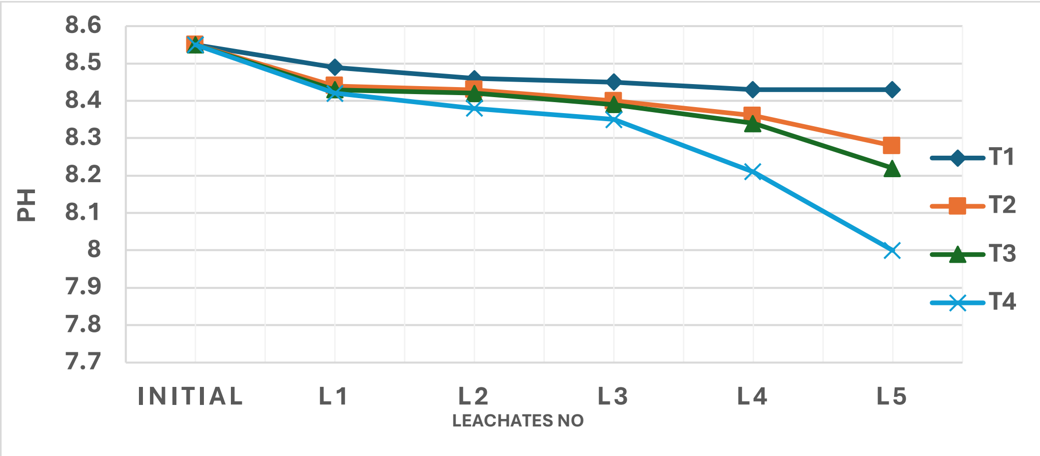

Fig. (2): Effect of different gypsum applications and number of leachates on (pH).

Sodium adsorption ratio (SAR): The changes in sodium adsorption ratio (SAR) affected by gypsum application rate and the number of leachates in our study are presented in Table (5) and Fig (3). The data indicated that all gypsum treatments caused a marked reduction in SAR values of the soil profile to a safe limit, where the mean reduction of SAR at the end of leaching processes were 10.73, 11.58, and 12.19 after gypsum used by 50, 37.5 and 25 t ha^{-1} respectively, with reduction of 56.55%, 53.11%, and 50.64% respectively as compared with the initial soil SAR (24.70). Also, data showed that the SAR was decreased to 18.88 for untreated plots (T1) where the reduction was 23.56% as compared with the initial SAR of the investigated soil, so, soil leaching alone without gypsum adding had no significant effect on SAR until it reached safe values. Also, the different gypsum treatments showed significant differences among them at the end of the leaching stage (Table 6) with the decreases in SAR as follows: T4 > T3 > T2 > T1 these results may be attributed to the amelioration effect of gypsum on physiochemical properties of the soil in the presence of sufficient amounts of leaching water, so gypsum provides adequate levels of Ca^{2+} cations to replace exchangeable Na^{+} on the exchange positions which removed with the infiltrating water as observed by Sharma and Minhas (2005). From the results, the effect of the number of leachate cycles on SAR values appears, where a high decrease occurs in SAR values at the start of the experiment (L1), recording a mean of 31.25% of the initial SAR value. despite this sharp decrease, is still higher than the critical limit (13%) due to the high amounts of exchangeable Na^{+} in the soil, where it was reduced recorded values that 14.75, 16.26 and 16.30 with gypsum-amended plots 100% GR, 75%GR and 50% GR respectively after the first leachate. The reason for this is the amount of calcium supplied from gypsum in the first leachate was not sufficient to expel enough exchangeable Na^{+} which makes SAR reach the safe limit. After that, with the continuation and repetition of leaching and mixing the remaining gypsum from the previous leachate with the soil surface, we found a decrease in the SAR values, as the effect of gypsum solubility appears (low solubility = 0.04%) with soil plowing between each leaching and the other, which gives gypsum a higher efficiency in the improvement process through the isolation of other quantities of Ca^{2+} in each leachate, in addition to the formation of more stable aggregates, which helps to expel more quantities of Na^{+} ions, and thus lower the SAR values to appropriate values. in spite of successive leaching cycles contributed to decreasing of SAR value, but the rate of SAR decrease in those leachates (L2, L3, L4, and L5) was less compared to the first leachate (L1) Also, our study revealed that the 100% GR treatment was superior to a decrease in the SAR value over the other treatments, this is consistent with what (Qadir *et al.,* 1996) reached, which attributed that to due increased displacement of exchangeable Na^+ due to increased soil solution Ca^{2+} from the applied gypsum, and subsequent leaching of the replaced Na^+ through percolating water under conditions of enhance soil aggregation. Also, in our study, we have observed a small, yet statistically significant reduction of SAR with the untreated plot (T1) reaching 23.56% at the end of the leaching processes, this was due to the "valence dilution" as demonstrated by Reeve and Bower (1960) for reclaiming sodic and saline-sodic soils, in a soil-water system where monovalent and divalent cations in solution are in equilibrium with the adsorbed cations, the addition of water to the system alters the equilibrium condition, this dilution of the soil solution favors the adsorption of divalent cations like Ca^{2+} at the cost of monovalent cations like Na^+, Which results in some decrease in SAR values. Also, the decrease in SAR of the untreated soil may be due to the provision of Ca^{2+} in the applied leaching water. Soil-$CaCO_3$ may also contribute to the supply of a part of the Ca^{+2}. In any case, those amounts were not enough to arrive SAR for the safe limit (<13%) therefore, soils needed to apply soluble calcium salts, e.g., gypsum, to take care of possible sodicity problems, where in sodic and saline-sodic soils when excess soluble salts are filtered out, it often occurs a problem of sodicity (Khosla *et al*., 1979).

Table (5): Effect of different gypsum application and the number of leachates on (SAR)

Treatments (T)	Number of leachates (L) L 1	L 2	L 3	L 4	L 5	Mean
T 1	20,60	20,11	19,56	17,14	16,97	**18.88**
T 2	16,30	12,10	11,66	10,90	9,96	**12,19**
T 3	16,26	12,02	11,68	10,12	7,83	**11,58**
T 4	14,75	11,67	11,27	9,26	6,69	**10.73**
Mean	16.98	13,98	13.54	11.85	10,36	
$LSD_{0.05}$	**(T) = 0.43, (L) = 0.48 and (T x L) = 0.96**					
Initial SAR						**24.70**
	T1, T2, T3 and T4 0.0, 25, 37.5 and 50 (t ha ^{1}) respectively					

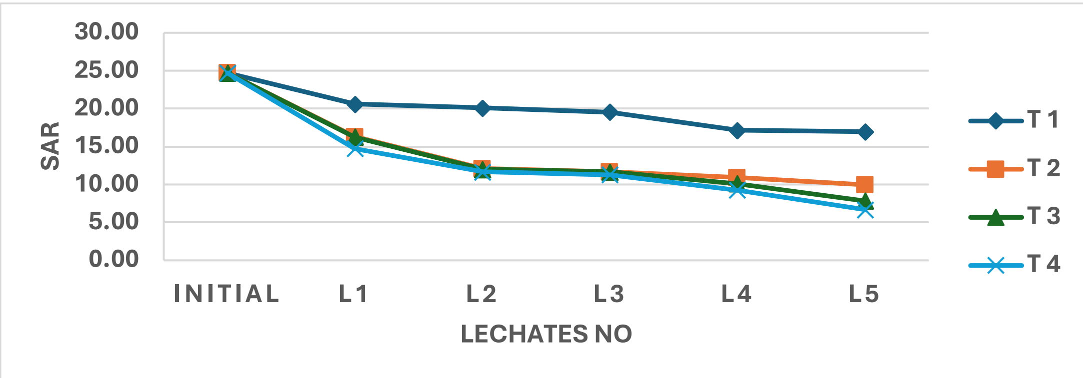

Fig. (3): Effect of different gypsum applications and the number of leachates on (SAR)

Exchangeable sodium percentage (ESP): As shown in Table (6) and Fig. (4), the exchangeable sodium percentage (ESP) dropped from initial soil ESP (37.90) to averages ranging between 34.32 to 60.10% at the end of the leaching processes. The highest decrease in ESP of the soil plots was observed when gypsum was applied at the rate of 100% GR (T4). So, the percentages of ESP decreasing for (T4) at the first, third, and fifth leachate were 47.75, 58.89 and 73.64 % respectively, compared to the initial value (37.90). ESP values decreasing for (T3) at the first, third, and fifth leachate were 43.37, 57.81 and 70.52 % respectively, compared to the initial value. Also, the percentages of ESP decreasing for (T2) at the first, third, and fifth leachate were 43.27, 57.75 and 63.62 % respectively, compared to the initial value. Whereas the control treatment (T1) recorded a decreasing percentage of ESP at the first, third, and fifth leachates 29.10, 32.79 and 41.13 % respectively, compared to the initial value. So, active desodification (decreased ESP) was observed in the order of T4 > T3 > T2 > T1 at the end of the leaching processes. The decline of ESP followed by gypsum treatments was due to the replacement of exchangeable monovalent Na^+ by divalent Ca^{2+} released from the used gypsum (Qadir *et al.,* 2001). Many studies have reported on this, where (Oster (1980), (Qadir *et al*., 1996), (Gharaibeh *et al*.,

2010) and Kim *et al*. (2018), reported that increasing Ca^{2+} ions released from the addition of gypsum could have improved the soil-aggregate formation and raised the hydrologic conductivity (HC), thus leading to eluviation of soluble salts such as Na^{+}. Also, Gharaibeh *et al*. (2009) show that the decrease in soil ESP with increasing application rates of the gypsum used may be attracted to increasing soil-solution Ca^{2+} resulting from gypsum adding and promoted displacement of adsorbed Na^{+} followed by subsequent leaching. That replacement of Na^{+} by Ca^{2+} explained the reduction in soil sodicity in the exchange colloidal complex and due to gypsum being a wealthy source of soluble Ca^{2+} (Gonçalo *et al*., 2019). In the same regard, from our data, in view of the rate of decrease in the ESP values after the third leachate (L3), recorded 16.01, 15.99 and 15.58 in T2, T3, and T4, respectively, it means that the exchangeable Na^{+} content in the soil plots was still high, so that average soil ESP was more than 15%, the classification criteria for sodic and saline-sodic soils which soil structure could be deleteriously affected, these requests implied that continuous treatment with gypsum and leaching to improved soil plots are required for further decline of ESP, so, that was achieved after the fifth leachate (at the end of the leaching process) where the ESP values became less than 15 in the three gypsum treatments T2, T3, and T4 giving a good indication of soil improvement. As for the decrease in ESP of the control plot (T1), moreover, in the soil-water system the soil solution favors the adsorption of divalent cations Ca^{2+} at the cost of monovalent cations Na^{+} when solution in case of equilibrium, this is due to the " valence dilution " as demonstrated by Reeve *et al*. (1960). Also, (Balba, 1961) demonstrated the reduction in soil ESP during the leaching alone to contribute to the soil-$CaCO_3$ providing a supplemental source for dissolved Ca^{2+}

Table (6): Effect of different applications and the number of leachates on (ESP)

Treatments (T)	Number of leachates (L) L 1	L 3	L 5	Mean
T 1	26,87	25,47	22,31	**24,89**
T 2	21,50	16,01	13,79	**17,10**
T 3	21,46	15,99	11,17	**16,21**
T 4	19,80	15,58	9,99	**15,12**
Mean	22.41	18.27	14.32	
$LSD_{0.05}$	**(T) = 0.67, (L) = 0.58 and (T x L) = 1.16**			
Initial $_{ESP}$				**37.90**
T1, T2, T3 and T4	**0,25,37.5 and 50 (t ha $^{-1}$) respectively**			

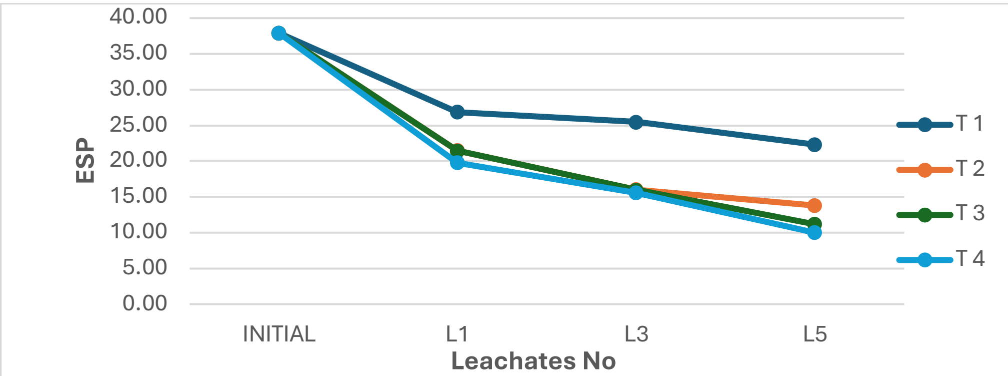

Fig. (4): Effect of different gypsum application and the number of leachates on ESP

CONCLUSION

Under intermittent leaching operations, the results showed a significant decrease in soil salinity, soil reaction and sodicity when gypsum was added at high rates (50 t ha^{-1} or 100% of GR), followed by 75% GR (37 t ha^{-1}), then 50% GR (25 t ha^{-1}). That is, the higher the gypsum percentage, the lower the soil's salinity, soil reaction, and sodicity compared to what was given by the control treatment. The results also showed that increasing the number of leachate cycles increases the improvement of soil salinity, alkalinity and sodicity, as the efficiency of the added gypsum increases with the increase in the number of leachates.

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دور إضافة الجبس والغسيل المتقطع في استصلاح الأراضي الملحية-الصودية بمنطقة القنطرة غرب ، الإسماعيلية ، مصر

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المستخلص: أجريت تجربة حقلية بمنطقة القنطرة غرب بالإسماعيلية – مصر ، لدراسة تأثير إضافة الجبس بمعدلات مختلفة على ملوحة وتفاعل (الرقم الهيدروجيني) وصودية الأراضي الملحية الصودية تحت ظروف الغسيل المتقطع (خمس غسلات) مع وجود صرف جيد. تم تقسيم الحقل الى أربع وحدات تجريبية كل وحدة بثلاث مكررات. تم إضافة الاحتياجات الجبسية المقدرة مسبقا ب 50 طن للهكتار على أربعة مستويات مختلفة صفر , 50%, 75% و100% من الاحتياجات الجبسية المقدرة مسبقا ب 50 طن للهكتار (0, 25, 5 . 37 و50 طن للهكتار على التوالي). أظهرت النتائج افضلية معاملة إضافة الجبس بمعدل 100% يليها 75% ثم 50% من الاحتياجات الجبسية مقارنة بالمعاملة بدون اضافة وذلك على ملوحة وتفاعل (الرقم الهيدروجيني) وصودية التربة . كما اظهرت النتائج تحسن خصائص التربة المدروسة بزيادة عدد دورات الغسيل المتقطع .