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Effect of residual Phosphogypsum on SAR and salinity level in profile of salt affected soil using saline ground water

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Abstract
A Field study was implemented during the two growing seasons (2017-2018 and 2018-2019) at Al-Tuwaitha research station, 30Km southeast of Baghdad. Phosphogypsum was applied with 6 rates (0, 25%, 50%, 75%, 100% and 125%) from gypsum requirements in salt- effected soil irrigated with saline ground water with EC of 3.2dS.m^{-1}. Results showed Highest reduction in SAR was found at 100% PG rate of addition it was 63.24, 53.08, 26.72 and 23.77 (%) for depths of 0-20, 20-40, 40-60 and 60-80 (cm) respectively compared with control (0PG). Although results showed that Electrical conductivity was found to be the least at 75% PG at all depths it was reduced by 41.10, 34.12, 24.89 and14.64(%) compared with control.

Keywords: Phosphogypsum, amendments, saline, sodic, ground water.

1. Introduction

Phosphogypsum (PG) is a waste by product from the processing of phosphate rock by the (Wet Acid Method) of fertilizer production (Renterıa-Villalobos, *et al.*, 2010) [10]. At the global level, the annual production of PG is about 300 Mt (Silva *et al.*, 2022) [23]. Only 15% of world PG production is recycled as building materials, agricultural fertilizers or soils stabilization amendments and asset controller in the manufactures of Portland cement (Mesic *et al.*, 2016; Saadaoui, *et al.*, 2017; Calderón-Morales *et al.*, 2021) [12, 21]. The remaining 85% is disposed of without any treatment. PG is composed mainly of gypsum ($CaSO_4 \cdot 2H_2O$) it contains elevated levels of impurities, which originate primarily from the source phosphate rock used in the phosphate fertilizer production. There is great interest in using PG as an alternative material for many applications. PG has been used in the cement industry to make gypsum plaster. PG also has been used as agricultural fertilizers or an amendment for the reclamation of degraded soils: saline, sodic, acidic, and alkaline soils (Nayak *et al.*, 2011; Mesic *et al.*, 2016 Saadaoui, *et al.*, 2017) [12, 21]. There have been numerous attempts in recent decades by researchers about the possibility of using Phosphogypsum for agricultural purposes and mainly focused their researches in the field for reclamation of sodic soils and saline sodic soils, mostly achieved remarkable success in this area (Shainberg, *et al.*, 1989; Al-Ghrairi *et al.*, 2004; Razaq *et al.*, 2006 and 2016; Agar, 2011; Al-Ghrairi *et al.*, 2021; Hasana *et al.*, 2022) [22, 5, 16-17, 1, 3, 27]. The researches shows that have been applied in this matter, that the use of Phosphogypsum has improved many of the physical and chemical properties related to replacing the calcium ion with the sodium ion in the exchange complexes, and thus enhance the structure of these soils and the subsequent improvement of water and air movement in the soil (Razaq *et al.*, 2006; Yaduvanshi, and Swarup. 2005; Ghafoor, *et al.*, 2001; Gharaibeh *et al.*, 2014; Outbakat *et al.*, 2022) [16, 25, 8, 9, 14].

The objective of this study was to evaluate the impact of different Phosphogypsum rates on soil salinity level and Sodium adsorption ratio (SAR) of different depths of salt-affected soil.

2. Materials and Methods

A field experiment was carried out at Al-Tuwaitha Research Station /Agricultural Research Directorate 30Km southeast of Baghdad, at salt affected soils. The field was divided into four blocks (replications) each block contains 6 experimental units with dimensions of 2 × 3 meter. The soil texture was silty clay, classified as a Typic Torrifluvent (Soil Survey Staff, 2006). Soil samples were taken from the depths of 0-20, 20-40, 40-60 and 60-80 cm, air dried, sieved through a 2.0 mm mesh, analyzed according to the standard methods described in Richards (1954) [19] and Page *et al.* (1982) [15] as shown in Table 1.

Table 1: Physical and chemical properties of soil.

Property		Value
Soil particles distribution (gm kg^{-1})		
Sand		67
Silt		398
Clay		535
Soil texture		Silty clay
EC 1:1 dS m^{-1}		18.20
PH 1:1		7.1
CEC (Cmol kg^{-1})		20.1
$CaCO_3$ (gm kg^{-1})		249.0
O.M (gm kg^{-1})		8.00
Available P (mg kg^{-1})		14.65
Available N (mg kg^{-1})		96.56
Available K(mg kg^{-1})		186.6
Soluble ions (mmol.kg^{-1} soil)	Na	123.80
	Ca	12.40
	Mg	18.10
	SO_4	32.55
	Cl	114.6
	HCO_3	1.78
SAR		22.40

The experiment was laid out using Randomized complete block design (R.C.B.D.) with three replications, the experimental unit area 6m^2, the number of experimental units reached to 6in each block, 1.5m separators was left between the blocks. Treatments consisted of six rates of Phosphogypsum (0, 25%, 50%, 75%, 100% and 125%) from gypsum requirements according to Richards (1954) [19] which equivalent to 3.250, 6.500, 9.750, 13.000 and 16.580 (t ha^{-1}) respectively were added in1/7/2017.
Saline ground water with EC of 3.5 dSm^{-1} and SAR of 12.1 was used in irrigation of the experiment by a series of plastic tubes and a special pump. Its properties are shown in Table 2.

Table 2: Properties of well water used in irrigation.

EC dS.m^{-1}	pH	Soluble ions (mmol.L^{-1})						
		Na^+	Ca^{+2}	Mg^{+2}	Cl^{-1}	SO_4^{-2}	HCO^{-3}	SAR
3.25	7.30	24.00	0.44	3.00	12.84	9.17	5.80	12.10

Barley crop, Samir variety were sown during the two growing seasons 2017-2018 and 2018-2019 with a rate of 160 kg. ha^{-1}. Recommended fertilization was added with nitrogen and phosphorous in the amount of 200 kg N. ha^{-1} and 80 kg P. ha^{-1} for all treatments. Phosphorous was added at sowing as triple super phosphate, while nitrogen fertilizer was added after sowing as a urea in three parts, 30% tailoring stage, 35% at booting stage, 35% at flowering. stage of Barley growth. Barley plants was harvested when it reached physiological maturity stage; dry matter and grains yield were recorded.

3. Results and Discussion

3.1. Characteristics of soil and water

Table 1 shows some of the physical and chemical properties of the soil used in this study. Soil salinity of surface layer as measured by 1:1 soil: solution ratio extract is 18.20 dS. m$^{-1,}$ pH is < 7.5 and SAR is more than 15. So, this soil is classified as a saline alkali soil according to (Richards, 1954 and FAO.1990) [19, 7].
Ground well water used in irrigation (Table 2) is relatively of high salt content expressed in terms of electrical conductivity with EC 3.25dS m^{-1}, SAR is 12.10, pH is 7.30 and, $CaCO_3$ content is 249 gm.kg^{-1}. Therefore, the ground water of this land used for irrigation is classified as saline water of class S_2 according to Soil Salinity Laboratory Staff classification of irrigation (Richards, 1954) [19]. So, high sodium content in the soil and ground well water coupled with heavy textured soil will lead to sever soil dispersion upon cropping (Shainberg *et al.*, 1992) [24]. Therefore, using of chemical amendments for such kind of calcareous soil is inevitable (Al-Ghrairi, 1998; Richards, 1954) [4, 19]. This may support the current investigation of application of PG or elemental sulfur as chemical amendments to prevents the accumulation of sodium salts in the soil profile and its re-salinization over time.

3.2. Soil Salinity (EC) at the soil depths

Figure (1) Shows values of soil salinity (dS m^{-1}) it was symmetrical in terms of direction at all depths. Phosphogypsum treatments showed that the highest value of salinity at control treatment (0PG) for all the soil depths and then decreases with increasing amounts of Phosphogypsum added to some extent added level 75% from the gypsum requirements then salinity increases at higher levels (100% and 125% from the gypsum requirements) to all the depths of the soil under study and this may be attributed to the increase release calcium and sodium in the soil solution and thus increase the electrical conductivity) Zahid *et al.*, (2006) [26]. These results also confirm that the EC of soil at any level of PG added increases with soil depth and possible be due to soil permeability decreases with soil depths, or the transmission of ions decreases with increasing depth of soil and this is agree with Khan *et al.* (2010) [11] and Hurtado *et al.* (2011) [10]. Mathematical analysis refers to these results that the best formula to describe them mathematically is a quadratic equation Curve linear as follows:

$Y=8.01 - 0.7402X + 0.0399X^2$, $R^2=0.971$,at depth 0-20 cm.
$Y=10.34 - 0.7816X + 0.0419X^2$, $R^2=0.951$ at depth 20-40 cm.
$Y=11.71 - 0.6913X + 0.0390X^2$, $R^2=0.7865$ at depth 40-60 cm
$Y=11.92 - 0.6077X + 0.0342X^2$ $R^2=0.6739$ at depth 60-80 cm.
Y= PG amount (T.ha^{-1}), X: Soli salinity

And it is clearly that the electrical conductivity of the control treatment at depth 0-20 cm was 8.15 dS m^{-1} decreases at a rate 0.7402,with increase of level of Phosphogypsum up to the level of 75% from the gypsum requirements, but it is increasing at a rate 0.035 multiplied by the square of quantity added extras that exceed 9.750 Tan. ha $^{-1}$ Phosphogypsum, while the electrical conductivity at depth of 60-80 cm 11.92 dS m^{-1} for the control treatment, reduce to 10.2 when increasing the Phosphogypsum up to the level of 75% from the gypsum requirements and increasing at a rate 0.03 to the square of the amount of Phosphogypsum added, and when comparing values electrical conductivity at the level 75% shows that the depth of 60-80 cm were up 12.0 dS m^{-1} while it 6.0 dS m^{-1} at depth 0-20 cm, an increase of 50% more than it is at depth 60-80 cm.

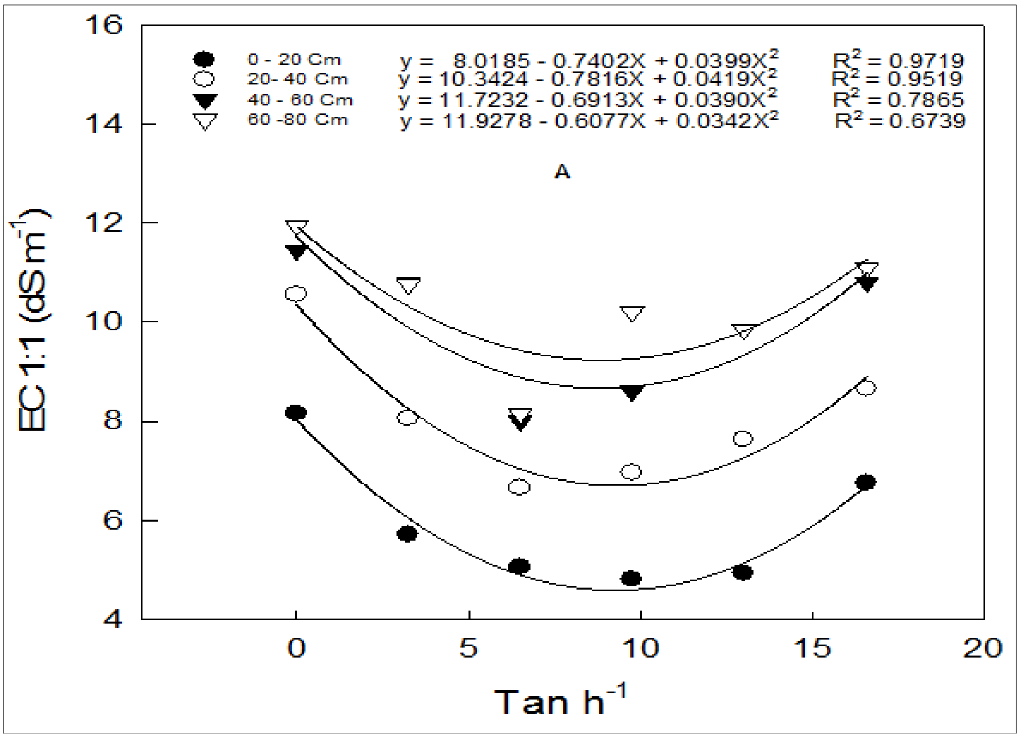

Fig 1: Effect Phosphogypsum on EC at different soil depths

3.3. Sodium Adsorption Ratio (SAR) at the soil depths

Sodium adsorption ratio (SAR) is one of the important criteria in the evaluation of soil salinity only but also by irrigation water too. Results shown in Figure 2 the amount effect of Phosphogypsum on the SAR value for soil depths 0-20, 20-40, 40-60 and 60-80 cm, it has been observed at the depth 0-20 cm which represents the surface layer of the soil a decrease of SAR for all levels addition of Phosphogypsum and this may be attributed to the role of Phosphogypsum in increasing calcium concentration in the soil, which inevitably leads to a decrease SAR in soil (Ager, 2011) [1]. Also, the decrease at a depth of 20-40 cm is similar to what it is at a depth of 0-20 cm and is close to it. As for the other two depths of 40-60 and 60-80 cm, the decrease in the soil SAR value less than it in the up depths for all levels of Phosphogypsum added, and this agrees with (Sancho *et al.* 2009 and Al-Ghrairi *et al.*, 2019) [2].

The results of the mathematical analysis of the relationship of the amount of phosphate gypsum used with the soil SAR values showed that the equation is of the Curve linear type and of the second order that describes these results according to the depths shown next to each of them, as follows:

At depth 0-20 cm: $Y=19.31 - 2.216X + 0.0954X^2$ $R^2=0.8713$.

And at depth 20-40 cm, $Y=22.41 - 1.871X + 0.0711X^2$ $R^2=0.9632$. Whereas, adding Phosphogypsum at the level of 100% and 125% of the gypsum requirements did not lead to a reduction in the rate of sodium adsorption into the soil at the two depths above (0-20 and 20-40 cm) compared to the addition level of 75% of the gypsum requirements.

While the following two equations are described the depths 40-60 and 60-80.

At depth 40-60 cm, $Y=21.93 - 0.8105X + 0.0297X^2$ $R^2=0.6138$, and $Y=23.60 - 0.8235X + 0.0276X^2$ $R^2=0.7780$ at depth 60-80 cm.

Y= PG amount (T.ha^{-1}), X: SAR

It is noted here that the increase achieved in soil SAR at these two depths is a slight increase, close to that increase at the same depths at the addition levels of 25%, 50%, and 75% of the PG, which can be described as a clear linear response.

These results also show the role of adding PG in reducing sodium content as express in term soil SAR for the various soil depths under study compared to the control treatment (without adding PG).

The results of the mathematical analysis also showed that the rate of displacement decreases with depth, as it was highest at 2.216 at the depth of 0-20 cm and decreased to 0.823 at the depth of 60-80 cm. This confirms that the greatest efficiency of Phosphogypsum was in the addition depth (0-20) cm and for this the result is an important field application in that Phosphogypsum must be mixed with the depth of the soil to be reclaimed.

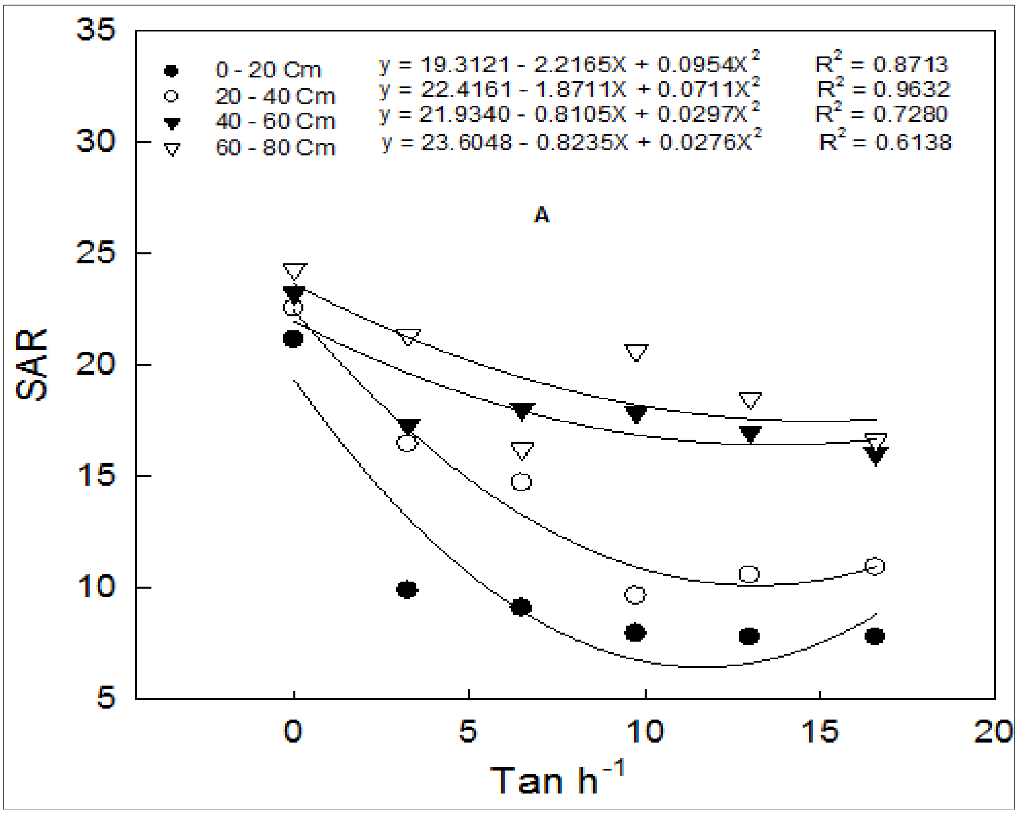

Fig 2: Effect Phosphogypsum on SAR at different soil depths

It also showed the SAR value of soil at different depths increases with depth, and this is consistent with previous findings in terms of sodium and calcium distribution in different soil layers, and is consistent with numerous researchers finding about the important role of chemical amendments in reducing of sodium content and salts redistribution in salt-affected soils especially with high calcium carbonate content and using saline water (Hasana *et al.*, 2022; Gharaibeh *et al.*, 2014; Razaq *et al.*, 2006; Al-Ghrairi *et al.*, 2004; Hurtado *et al.* 2011) [27, 9, 5, 16, 10] about the role of Phosphogypsum in the redistribution of salts in the soil. The results of mathematical analysis also showed displacement rate decreases with depth, where was higher (0.982) at 0-20 cm depth and decreased to 0.041 at 60-80 cm depth, and this confirms that the greatest efficiency of Phosphogypsum added was in depth (0-20 cm), and to this result important of applications fields in terms of the necessity of mixing Phosphogypsum with the soil.

4. Conclusion

1. Based on the results of this study, when adding any chemical amendments such as Phosphogypsum it is must be mixed with the depth of the soil to be reclaimed, because this is more effective in reducing the salts level and improving the properties of reclaimed soils.
2. It is necessary to monitor the residual effect of PG for more than one season in subsequent studies to determine the optimal time for repeating the application according to the conditions of the reclaimed soil and the condition of the cultivated plants.

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