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Gypsum and Nano-Gypsum Effects on Certain Soil Characteristics and Sorghum Yield under Saline-Sodic Soil Conditions

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A POT EXPERIMENT was carried out to evaluate the efficiency of nano-gypsum comparing with conventional gypsum on some soil properties and sorghum crop growth. Soil was collected from Sakha, Kafr El-Sheikh Governorate, Egypt. The nano-crystalline structure of the synthesized material with an average size of about ≈ (42.5 to 66.5) nm was observed by the SEM micrographs. The study was carried out in a completely factorial randomized design (FCRD), with two modifications included. Nano-gypsum (NG) and traditional gypsum (CG) were specified for four different gypsum-requirements (GR), namely 25, 50, 75, and 100%. The experiment was three replicates. Soil was analysed for pH, EC, exchangeable cations investigation's findings demonstrated that 100% GR as Nano-gypsum decreased soil salinity (EC) and ESP at the highest rate, reducing EC to 1.20 and ESP to 10.20, and 75% (GR) as Nano-gypsum decreased EC to 1.66 and ESP to 12.69. In contrast, 100% GR as conventional gypsum decreased EC to 1.84 and ESP to 13.30. Overall, saline-sodic soil was significantly and very effectively improved by both 100% and 75% GR Nano-gypsum, which also increased sorghum yield and growth over 100% GR conventional gypsum. According to this study, applying 75% GR as Nano-gypsum is more efficient than using 100% GR as regular gypsum.

Keywords: Agricultural gypsum, Nano-gypsum, Sodic soils, Saline soils, Soil properties, Sorghum plant.

1. Introduction

There is worldwide concern about soil degradation resulting from soil formation and salinization. (Hassani *et al.,* 2020 and FAO, 2021) states that the area of soils affected by salt was estimated to be 11.74 million km^2 worldwide, and Asia, Africa, and Australia are the continents which contained the highest areas. The majority of Egypt's soils that are affected by salinity are found on the eastern and western flanks of the Nile Delta as well as in its north central region. Nonetheless, salty soils impact 55% of the North Delta region's arable land, 20% of the southern Delta and central Egypt regions, and 25% of the Upper Egypt region (El-Shaarawy *et al.,* 2008). Soils affected by salt represent a large part of the agricultural land about 30% of the total cultivated area in the Delta and Upper Egypt. In such soils, the hydrological conditions are very complex (Abdel-Dayem *et al*., 1978 and FAO., 2005). according to (Amer and Hashem 2018) saline and saline sodic soils are most prevalent in the North Delta region (46%) duo to irrigation with saline drainage water and poor drainage both promote the buildup of sodicity and salinity. Because precipitation exceeds evaporation in semi-arid regions, saline and sodic soils have their origins there (Qadir *et al.,* 2008). It occupied about one-third of Egypt's Nile Delta, the promotion of soil degradation threatens the remaining areas (Mohamed, 2016). Although over half of the soils in the Kafr El-Sheikh Governorate (North Nile Delta, Egypt) are affected by salinity (Abdel Rahman *et al.,* 2019; Aboel Soud *et al.,* 2022).

Saline soil improvement is a key component of Egypt's program for agricultural security. Saline soils with an excess of soluble salts present in amounts that hinder the growth of most crops. It is identified by a pH > 8.5, EC > 4.0 dS/m and ESP >15 Because of their poor physico-chemical qualities, these soils pose a significant threat to crop production (Mohamedin *et al.*, 2005 and Matosic *et al.*, 2018).

Degradation of saline-sodic soils as a result of sodium and salinity acting simultaneously. As a result of clay swelling and dispersing, the soil loses some of its physical structure (Young., 2016). Suggestions for enhancing and controlling soils impacted by salinity. first, to recover soils impacted by salt; second, to manage soils impacted by salinity, that is, without reclamation, by employing suitable substitute options for agriculture, such as saline

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aquaculture and plant cultivation that can tolerate more salt. The choice is based on how economically and practically reclamation can be done (Mandal *et al*., 2018; Yonggan *et al*., 2020; El-Ramady *et al*., 2022). Ali and Kahlon. (2001) stated that simple leaching was ineffective for reclaiming saline and sodic soils. These soils require more time, effort, and money to recover than saline soils because calcium has been substituted for replaceable sodium. Therefore, it necessitates the addition of chemical adjustments like gypsum with leaching. They went on to say that the following factors affected how effective gypsum was (i) its level of softness, (ii) how it was mixed into the soil and (iii) how well the drainage system worked.

Reclaiming sodic soils, the oldest type of soil modification, with gypsum technology ($CaSO_4.2H_2O$) (Kost *et al*., 2018 and Presley *et al*., 2018). Due to its solubility, affordability, and availability, gypsum is the most commonly used amendment for reclamation sodic soil and minimizing the negative effects of high-sodium irrigation water, which is harmful to agricultural areas (Amezketa *et al*., 2005; Hafez *et al*.,2015). By facilitating the efficient removal of Na^+ at soil exchange sites through increased exchangeable Ca^{+2}, gypsum application mitigated hazardous impacts (Aboelsoud *et al*., 2020). This increases slurry accumulation, which in turn increases water infiltration and movement through the soil's enzyme-physicochemical properties (Fontoura *et al*., 2019; Aiad *et al*., 2019 and Zhang *et al*., 2020). (Singh and Bajwa, 1991) discovered that utilizing gypsum in the reclamation of sodic soil improved the elimination of dissolved sodium and decreased the pH and ESP of the restored soil. Reclamation was accelerated when more redundant gypsum was added and water with a high specific absorption rate was used for filtration. (Koriem *et al*., 1994) gypsum treatment was found to be more effective in lowering EC, dissolved ions, ESP, exchangeable Mg^{+2} and raising exchangeable Ca^{+2} in addition to enhancing all physical properties. The salt-affected soil characteristics induce physiological and morphological changes, decreases leaf water potential, increased ion toxicity, alter the biochemical processes in plants; and the photosynthesis process. This reflects subsequently on crop production (Doklega *et al*., 2021; Shrivastava and Kumar.,2015; El-Nahrawy *et al*., 2022 and Evelin *et al*., 2019) .Soil salinity greatly influences the decline in yield potential of cultivated crops, as crop yields begin to decline when the electrical conductivity value exceeds 4.0 dS/m (Mohamed., 2016).Salinization can lead to a 10-25% decrease in yields for many crops, as salinity affects plant growth by creating osmotic imbalances and specific ionic toxicities (Parida *et al*., 2005). Use of 960 kg NG ha^{-1} decreased ESP and EC_e, (Abd El-Halim et al., 2023). Ghazi et al. (2022) revealed that increasing amount of nanoparticles in amendments become a positive effect in all soil properties studied. Farmers must be used combinations of gypsum and compost to improve plant growth and soil properties especially under salt affected soil conditions (El-Sherpiny and Kany, 2023). Any adding of humic acid from different sources only or combination with Ca and Fe increased the dry matter and growth parameters of Sorghum, (Hamad and Tantawy, 2018). Abdelhamid et al. (2024) revealed that integrated use of gypsum and organic compounds improve plant growth and soil properties (i.e., EC, pH and ESP). The reclamation of sodic soils has historically been advised by gypsum.

This work aims to study the effect of adding nano-gypsum comparing with traditional-gypsum and its effect on soil properties and sorghum crop growth.

2. Materials and Methods

For achieve the aim of this study, we search about alkaline soil which met the following characters: electrical conductivity of soils paste extract > 4 dS/m, pH >8.5 and exchangeable sodium percent > 15%. This soil was collected from the Sakha agricultural research station farm, Kafr El-Sheikh, Egypt and analyses for the initial physio chemical properties, Table (1).

A pot experiment was carried out with the primary objective of assessing the efficiency of nano-gypsum in reclamation of alkaline soils comparing with convention gypsum with (sorghum) as test crop. The experiment was conducted in the summer season 2021, (Fig. 1). Use calcium sulphate dehydrate product from chemical company as a source of CG and material for preparing NG. NG prepared by manual grinding in ceramic mill for 7 hr. Nano-gypsum was synthesized and characterized at Kafrelsheikh University, faculty of Science, Nanotechnology lab. Morphology was observed by the scanning electron microscope (FEG SEM, THERMOFISCHER, QUATTRO S, NL). The sample was sputter coated with gold for 1 min and examined at 10 KV. Furthermore, the elements were also studied using energy dispersive x-ray spectroscopy technique (EDX) using the silicon – drift SEM EDS detector (energy resolution about 129 eV or better, SEM, JEOL JSM-IT100).) With the analysis condition of WD 10 mm and voltage 20 KV. Additionally, size and crystal structure of the synthesized material using x-ray diffraction (XRD) technique (a Shimadzu – XRD 6000, X-ray diffractometer with Cu Ka radiation (k = 1.5418 Å).

Four levels of evaluation were conducted between nano-gypsum and conventional gypsum, with one control.

The Factorial Completely Randomized Design (FCRD) was used to set up the experiment, and it was repeated three times. After draining the water, the leachate was gathered. This was done twice: the leachate was collected and its exchangeable ions were tested to assess the efficacy of any reclamation properties of NG and to compare its efficiency to that of CG. Plastic pot with 5 kg of soil and 5 holes in bottom of bags to drains was used. Each pot holds five plants of Sorghum hybrid 102 which cultivated in 20th June 2021 and harvest three cutting, 1st cutting in 2nd Aug. 2021, 2nd cutting in 27th Aug. 2021 and the 3rd were cutting in 23th Sep. 2021. All treatments received 150 kg/fed of mono superphosphate (15.5% P_2O_5), 50 kg/fed. Of potassium sulphate (48% K_2O) and 220 kg/ fed of urea (46.5% N), all agronomy practices are done as recommended by Ministry of Agriculture, Egypt. In order to achieve this, a fixed amount of water (2.6L) was added each time and thoroughly mixed.

For all treatments, bulk soil samples were taken before and after harvesting, shade dried ground with a wooden mallet, sieved through a 2 mm sieve, and stored for physical and chemical analysis. Salinity was determined in soil paste extract, electrical conductivity and pH 1:2.5 were measured using a portable EC and pH meters, cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) according to (Page *et al.*, 1982).

Gypsum was the soil amendment utilized in this experiment; the amounts of CG and NG amendments were added to the soil and mixed in surface layer (0-20cm of soil) in accordance with the gypsum requirements (GR) to the respective treatments as 4.74, 9.47, 14.21 and 18.94 g gypsum per pot to 25, 50, 75 and 100% GR, respectively. The CG used was the $CaSO_4.2H_2O$ of 85% purity.

A GR calculation was made. Four levels of evaluation were conducted on the two sources, namely nano-gypsum and conventional gypsum, with one control. The (FAO and IIASA 2000) guidelines were used to calculate the gypsum ($CaSO_4.2H_2O$) requirements (GR) in order to lower the initial ESP for the soil matrix to 10% according to the following equation:

$$GR = \frac{ESP_i \text{ -}ESP_f}{100} \times CEC \times 1.72 \times \frac{42}{purity}$$

Where:

GR= gypsum requirement (Mg/fed.=3.788), ESPi: initial soil ESP, ESP_f: The desired soil ESP, and CEC: cation exchange capacity (cmolc/kg); 1.72 tons is the amount $CaSO_4.2H_2O$ required to reduce the Na^+ content of the soil and 42 to convert amount per ha. to fed.

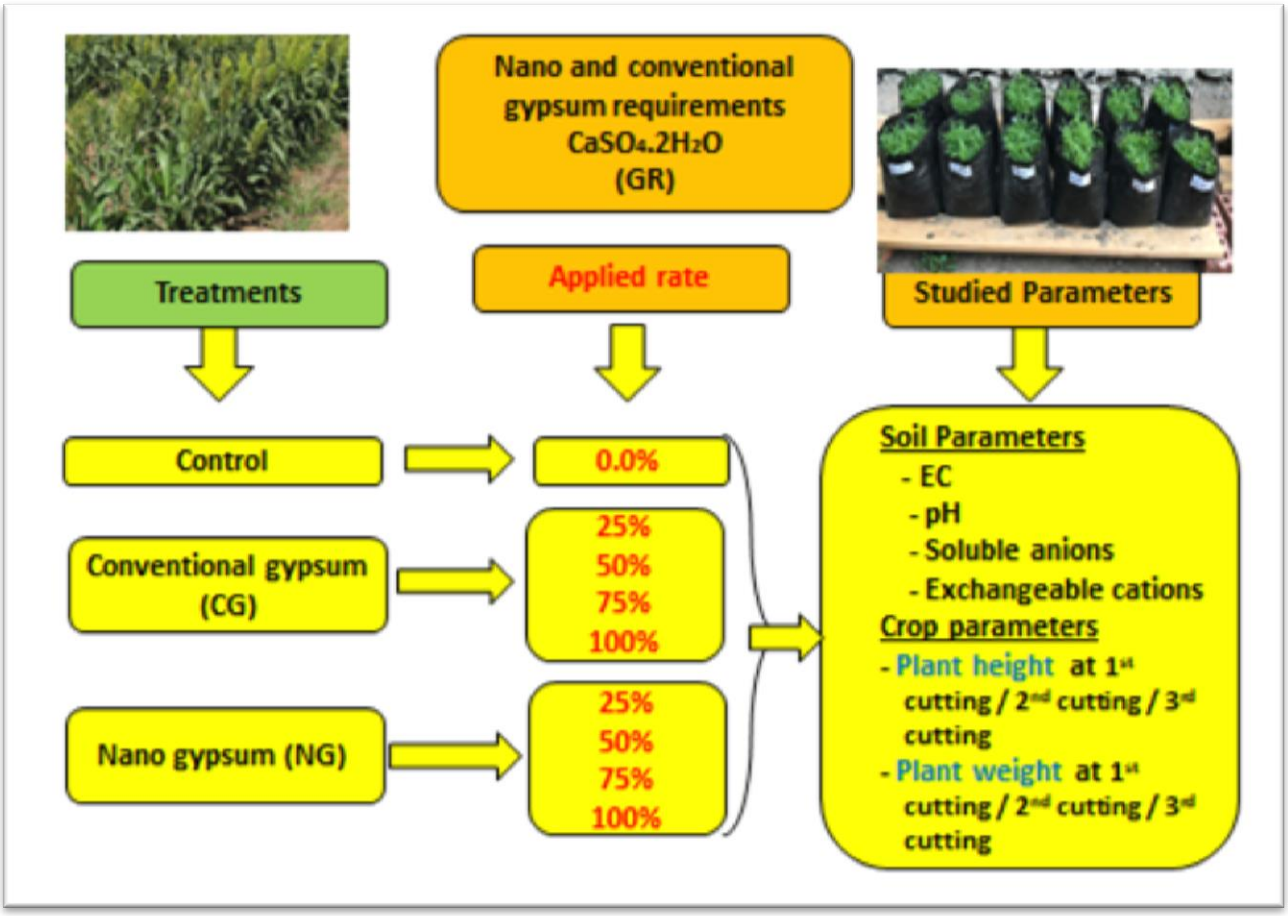


Fig. 1. The flowchart of the current experiment.

Table 1. Physico-chemical properties of the soil before adding soil amendments.

Properties	value
Particle size distribution, %	
Sand	17.20
Silt	28.26
Clay	54.16
ECe, dS m^{-1} (soil paste extract)	18.50
pH (1:2.5 soil suspension)	8.81
Soluble anions, mmolc L^{-1}	
Na^+	122.25
K^+	2.20
Ca^{++}	27.50
Mg^{++}	20.00
Cl^-	82.50
HCO_3^-	9.00
$SO4^{--}$	80.45
CEC, cmolc kg^{-1}	38.52
Exchangeable cations, cmolc kg-1:	
Na^+	8.31
K^+	1.00
Ca^{++}	16.09
Mg^{++}	13.01
ESP, %	21.57

3. Results

The nano-crystalline structure of the synthesized material with an averge size of about ≈ (42.5 to 66.5) nm was observed by the SEM micrographs shown in **Figure 2 A-B**. Furthermore, the high purity of the synthesized NPs was confirmed by the SEM - EDX microanalysis shown in Figure 1c. The EDX pattern exhibited the characterstic peaks of O, S and Ca at 0.525, 2.307 and 3.690 Kev with a molar ratio of about 72.35, 14.54 and 13.11 %, respectively.

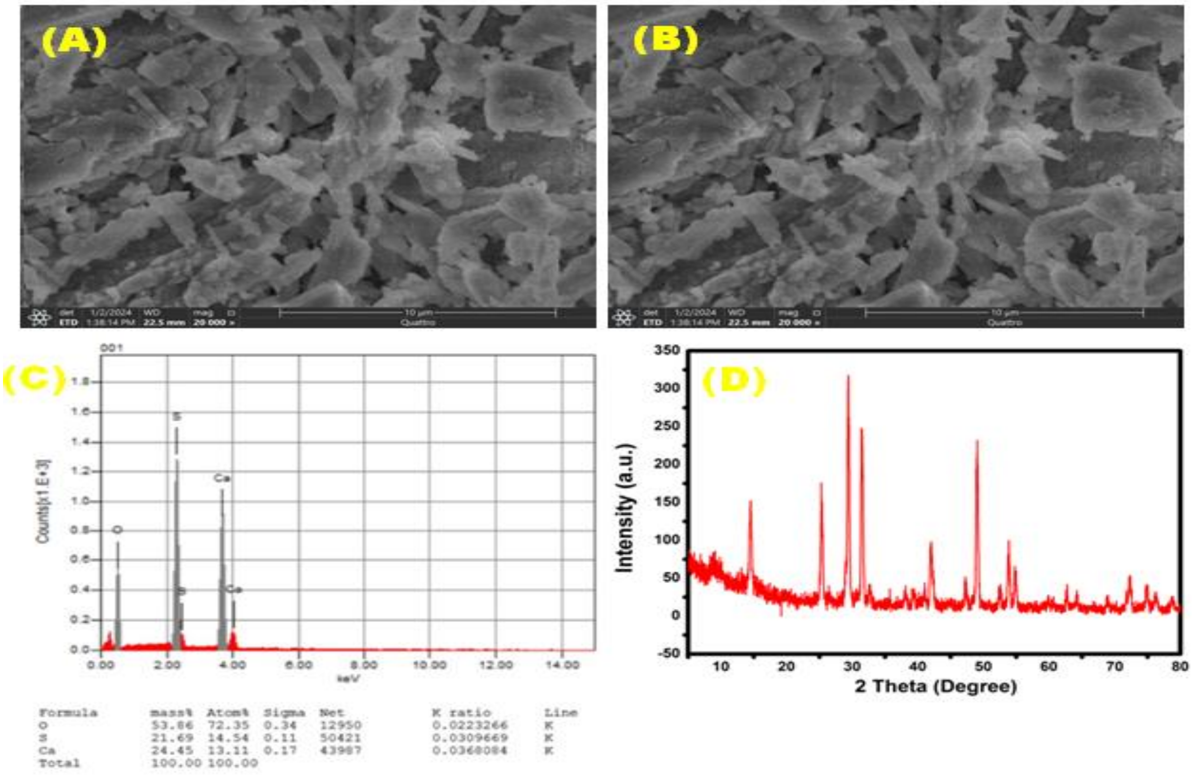
Besides, the XRD pattern showed five crystalline peaks characterstic of calcium sulphate at 14.47, 25.41, 29.38, 31.48, 42.06 and 48.82. Also, the increase in the intensity of diffraction peak at 29.38 than 31.48o assured that the prefereential growth of crystal at the plane 004 than 204, (Wang et al., 2008). (Fig. 2) illustrated the XRD patters of nano-gypsum that appeared at 2ϴ = 14.47855, 25.3348, 29.3899, 31.4785, 48.9793, 53.7966, and 72.2350. The characteristic patters matched with calcium sulphate, this result emphasized the purity component of the nano product.

The grain size of nano-gypsum was calculated from (Scherrel's equation) as follow:

$$D = \frac{0.9\lambda}{P \cos \Theta}$$

The grain size of nano gypsum was (42.5 to 66.5) nm.

Data presented in Table 2 and Fig. 3 showed the effect of adding rate and types of gypsum on soil salinity and pH. It has been noted that the profound change in the soil pH with addition of NG and CG at varying levels of application based on GR. The lowest decline of pH occurred in control (1.13%) and decreased by (7.48%) in the 100% NG treatments followed by (6.16%) in 75% NG on par with 100 % CG (5.21%). EC_e was a significant reduction in the soil's electrical conductivity (EC) has been observed subsequent to the application of gypsum. The largest reduction in EC was found in 100% NG was used (59.45%) followed by the application of 75% NG (43.68%) which proved to be more successful than applying 100% CG (37.83%) followed by 50% NG (36.71%).



Formula	mass%	Atom%	Sigma	Net	K ratio	Line
O	53.86	72.35	0.34	12950	0.0223266	K
S	21.69	14.54	0.11	50421	0.0309669	K
Ca	24.45	13.11	0.17	43987	0.0368084	K
Total	100.00	100.00				

Fig. 2. Characterization techniques of CaSO4; (A-B) SEM micrographs, (C) EDX spectrum and (D) XRD pattern.

Table 2. Effect of nano-gypsum (NG) and conventional -gypsum (CG) on soil pH and salinity (EC_e, dSm^{-1}).

Treatment	Soil pH		Soil salinity (EC_e, dS m^{-1})	
	NG	CG	NG	CG
Control	8.71	8.71	16.69 a	16.69 a
25% GR	8.45	8.60	13.44 d	15.25 b
50% GR	8.36	8.47	11.69 e	14.31 c
75% GR	8.26	8.42	10.38 f	13.13 d
100% GR	8.15	8.35	7.50 g	11.50 e
F-test	-	-	**	**

GR: gypsum requirements, **NG**: nano gypsum; **CG** conventional gypsum; **** significant at 0.01 level

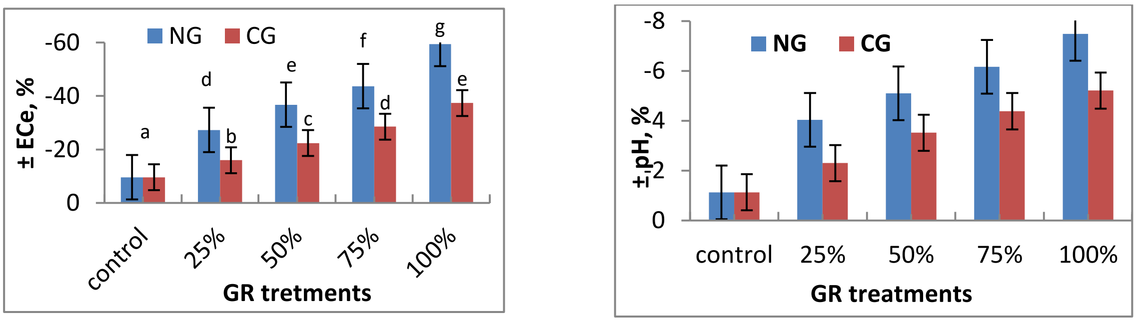


Fig. 3. The relative change percent (± %) in EC_e and pH values as affected by adding NG and CG.

Data presented in Table 3 and 4 showed the effect of adding amendments on Exchangeable cations and Exchangeable Sodium Percentage (ESP). The amendments had a major impact on the ratio of exchangeable sodium and exchangeable sodium percentage. Comparison between the two sources, NG treatments recorded the lowest values of exchangeable sodium with the highest rates of decline. The treatment of 100% NG recorded the lowest value for exchangeable sodium, as it recorded the highest value of decrease (51.74%) followed by 75% NG. The exchangeable sodium levels declined by (40.50%) Compared to the control, which recorded the lowest value for exchange sodium, which recorded the lowest drop (7.17 %), The application of 100 % CG recorded a decrease by (37.74%) and the application of 75 and 50% CG dropped by 32.20 and 25.91%, respectively.

Exchangeable Sodium (ESP) the same trend in replaceable sodium was observed, where the control recorded the lowest decline in ESP 6.87%, and the highest low was in 100 and 75% NG 52.71 and 41.14% respectively, followed by100 and 75 % CG 38.33 and 32.55%.

Exchangeable calcium: the lowest value of exchangeable calcium was recorded with the lowest rate of increase in control 4.74% respectively, the highest value of exchangeable Ca^{+2} was recorded in100% NG with the highest rate of increase 35.52% followed by 75% NG 28.27 % compared to using 100% CG, which increased by 26.88%, the exchangeable Ca^{+2} increased more quickly when using 100% and 75% NG. The highest exchange rates of Ca^{+2} were found in correlation with increased amendment levels. In the reclaimed soil, a noteworthy impact of amendments was noted on the exchangeable Ca^{+2}.

Exchangeable magnesium: the decrease in exchangeable Mg^{+2} indicates the effectiveness of NG in reducing the percentages of exchanged magnesium in the soil compared to CG. Where the lowest rate of decline was in 1.22 % and the highest decrease was in 100% NG 6.86%. Conversely, 100% CG, showed a 5.25% decline rate. Over all among the amendments NG recorded significantly lower exchangeable Mg^{2+} over CG. Among the levels, 100%, 75% and 50% GR were on par.

Exchangeable potassium: in soil reclamation, the impact of amendments and their concentrations was not statistically significant in relation to exchangeable potassium.

Table 3. Effect of adding NG and CG on soil exchangeable cations, cmolc kg-1.

Treatments		Na^+	Ca^{+2}	Mg^{+2}	K^+	CEC	ESP%
Control		7.71a	16.85g	12.89a	1.00a	38.39	20.08a
NG	25%	6.24c	18.51e	12.79a	0.97b	38.56	16.18c
	50%	5.71d	19.50c	12.60b	0.94c	38.77	14.72d
	75%	5.09f	20.64b	12.38d	0.92d	38.93	12.69 f
	100%	4.01g	22.14a	12.11e	0.91e	39.23	10.2 g
CG	25% GR	7.08b	17.71f	12.78a	0.99b	38.39	18.38b
	50% GR	6.19C	18.87d	12.63b	0.98b	38.57	15.93c
	75% GR	5.63d	19.63c	12.45c	0.95c	38.71	14.54d
	100% GR	5.17d	20.34b	12.32d	0.94c	38.88	13.3 e
F-test		**	**	**	**	ns	**

NG: nano-gypsum**; CG:** conventional-gypsum**; ****: significant at 0.01 level**; ns**: not significant

Table 4. The relative change percent (± %) as affected by adding NG and CG on soil exchangeable cations and ESP%.

Treatments		Na^+	Ca^{+2}	Mg^{+2}	K^+	ESP%
Control		-7.17	+4.74	-1.22	0	-6.87
NG	25%	-24.90	+15.03	-1.53	-2.33	-24.98
	50%	-31.24	+21.23	-3.12	-5.33	-31.75
	75%	-40.50	+28.27	-4.78	-7.3	-41.14
	100%	-51.74	+35.52	-6.86	-8.67	-52.71
CG	25%	-14.75	+28.58	-1.76	-1	-14.89
	50%	-25.91	+17.27	-2.86	-2	-26.22
	75%	-32.20	+22.01	-4.24	-4.67	-32.55
	100%	-37.74	+26.88	-5.25	-5.67	-38.33

Data presented in Table 5 showed the effect of gypsum adding on Sorghum growth and yield. The results showed that the highest productivity per fed. of sorghum can be obtained by adding 100 and 75% NG where 100% NG recorded the highest tall of one plant 103.32 cm and the heaviest plant 13.48 gm, comparing to control which recorded the shortest plant length 45.39cm also the lightest weight of one plant 2.13 gm.

Table 5. Selected growth properties attribute of sorghum plant.

Treatment		L1	L2	L3	Mean	W1	W2	W3	Mean
Control		41.33 e	36.46 d	58.40 d	45.39	2.53 g	1.86 e	2.00 d	2.13
NG	25	74.46 dc	65.93 c	71.86 c	70.75	5.73 e	4.9 d	6.06 cd	5.56
	50	89.53 bc	83.86 abc	86.13 ab	86.50	8.6 d	8.2 b	10.53 ab	9.11
	75	107.40 ab	87.20 ab	92.90 ab	95.83	10.86 bc	8.9 b	12.33 ab	10.69
	100	115.86 a	99.06 a	95.06 a	103.32	15.13 a	12.33 a	13.00 a	13.48
CG	25	56.46 de	67.90 bc	54.43 d	59.59	3.80 f	4.03 de	2.83 d	3.55
	50	97.26 ab	69.80 bc	78.93 bc	81.99	7.73 d	6.00 cd	5.73 cd	6.48
	75	98.13 ab	78.93bc	88.6 ab	88.55	10.06 c	7.46 bc	8.26 bc	8.59
	100	104.46 ab	81.00 abc	91.83 ab	92.43	11.53 b	9.40 b	10.26ab	10.39
F-test		**	**	**	-	**	**	**	-

NG: nano-gypsum**; CG:** conventional gypsum **L1:** length of plant(cm) after the first cut**; L2:** length of one plant (cm) after the second cut**; L3:** length of one plant (cm) after the third cut **W1:** weight of one plant (gm) after the first cut**; W2:** weight of one plant (gm) after the second cut**;** W3: weight of one plant (gm) after third cut**.**

4. Discussion

The soil pH before experiment was 8.81 and upon reclamation using conventional gypsum (CG) and nano-gypsum (NG), the pH significantly reduced by7.48% after the first crop and 1.1% after the second crop. The effect of the amendments in significantly lowering soil pH can be seen from controlling all levels of application. The role of $CaSO_4$ $2H_2O$ in flooded soils was well defined in this study, as there was a substitute of Ca^{++} from the amendments by Na^+ on the exchange soil complex. Because of its finer particle size and greater surface area, NG may have contributed significantly to the pH drop by enhancing the dissociation of $CaSO_4$ $2H_2O$ in the submerged state. Similar results highlighting the lower soil pH due to traditional gypsum application have also been reported by (Hussien *et al.*, 2022; Chauhan 1992; Ilyas *et al.*, 1997; Patel and Suthar., 1993 and Duraisamy *et al.*, 1986). When the volume of the substrate or the carrier material is reduced, the surface area correspondingly increases, thus NG can help exchange more sodium than conventional gypsum. The pH of the soil may have significantly decreased as a result of these processes.

A significant decrease in EC was recorded by the application of NG and CG at all levels compared to the control, decrease in EC was recorded with the increase of the amendments which clearly attributed to the removal of dissolved salts during the extraction process, especially the ponds and surface filtration, this similar change in EC was reported by (Sharma *et al.,* 1991 and Ilyas *et al.*, 1997). In this study NG recorded higher efficiency in reducing EC, the decrease in soil salinity can be attributed to the higher specific surface area of NG as opposed to CG. This increase in surface area allows for greater opportunities for sodium exchange.

ESP reduced significantly as a result of amelioration of alkaline soil with CG and NG which reduced Na^+ ion concentration in the exchange complex. The leachate contained a higher concentration of sodium ions, indicating the effective role of gypsum in replacing sodium ions from the exchange complex. Regardless of the sources, whether CG or NG, the restorative effect was recorded with increasing levels of modifications. This indicates that increasing the amount of Ca^{+2} supplied through amendments, increasing the substitute of Na^+ ions from the soil complex leads to a reduction of exchangeable Na^+ and ESP. The decrease in soil micelle sodium saturation by amendments could be mainly due to an increase in the dissolution of gypsum and an increase in the partial pressure of soil carbon dioxide (Chhabra and Abrol., 1977). (Kumar and Singh. 2003) confirm the results of this study. They reported an ESP less than 15% in all gypsum treatments with different levels of GR and the values were much lower compared to ESP of the soil before study. Also (Ghafoor *et al.,* 2001) reported an increase in the effect of softness of gypsum. The larger the surface area, the higher the solubility ratio and it can effectively reclaim soils. There is a wealth of evidence regarding the effectiveness of amendments in reclaiming alkaline soils. The application of 75% NG (2.841 Mg/fed) decreased ESP by 41.14%, which was higher than the reduction of 100% CG (3.788 Mg/fed) 38.33%. The highest rate of decline in ESP, 52.71%, was recorded in 100% NG; on the other hand, the lowest decrease was 14.89% in 25% CG.

The results of exchange cations indicated to the ability of both CG and NG to reclaim alkaline soil. The low concentration of Na^+ and the higher concentration of Ca^{+2} in the exchange complex indicate to the positive effect of NG and CG in the reclamation of alkaline soil, but it was noted that NG treatments at all levels has accumulated more Ca^{+2} and less Na^+ in the exchange complex than CG. The higher effect of NG in replacing Na^+ from the complex over that of CG could be attributed to the finer particle size, higher CEC and solubility of NG. The increasing of levels of gypsum increase exchangeable Ca^{+2}. It could be showing that the higher of the quantity of Ca^{+2} supplied as $CaSO_4.2H_2O$, the higher the replacing power and reclamation, which confirm that the increase in the concentration of Ca^{+2} in the exchange sites increase with the increasing of the levels of amendments applied (Ilyas et al., 1997 and Patel and Suthar 1993). For Mg^{+2}, the difference between the treatments is not large, but there is a clear and noticeable difference from the control, which may be due to the substitution of Mg^{+2} from the exchange sites. A slight but non-significant decrease in exchangeable K^+ was recorded which may be due to the occupation of K^+ exchange sites in the soil by Ca^{+2} during the reclamation process.

5. Conclusions

According to the findings of the current study, it was found that pH decreases in the CG and NG treatments, and there was also a gradual decrease in the acidity with the gradient in the levels of the added gypsum. The use of 100% NG has been shown to lower pH by 7.48%, and the use of 75% NG has been shown to record a drop rate higher than that of 100% CG, at 6.61 and 5.21%, respectively. Both CG and NG considerably reduced the EC of the soil. it was discovered that in terms of lowering the EC of the alkaline soil during reclamation, control had the lowest rate of decline (9.56%), while 100% NG had the highest decrease (59.45%). 75% NG was comparable to 100% CG. Exchangeable sodium record a promiscuous decline where the exchanged sodium recorded the highest rate of decrease 51.74% in 100% NG and the corresponding ESP was decreased by 52.71%. Both of 75% NG and 100% CG were on par in reducing the exchangeable Na^+ in the clay micelle.

Conflicts of interest: Authors have declared that no competing interests exist.

Author contribution: Ahmed El-Henawy, MR Khalifa and SA Gaheen are contributed in this article as supervision committee of Heba El-Faramawy is M Sc students. All authors have read and agreed to the published version of the manuscript.

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