Assessment of Gypsum as a Soil Ameliorant on Salt-affected Soils in the Ho-Keta Plain of the Volta Region, Ghana

L. Sackey[1*], E. Osei[1], E. O. Bennoah[2] and A. Tettey[3]

[1]*Soil Research Institute, Ghana.*
[2]*Department of Soil Science, University of Ghana, Ghana.*
[3]*International Institute of Tropical Agriculture (IITA), Accra, Ghana.*

Authors' contributions

This work was carried out in collaboration among all authors. Author LS designed the study, wrote the protocol and wrote the first draft of the manuscript. Author EO managed the literature searches, Author EOB edited the draft and author AT managed the statistical analysis of the study. All the authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Aims: To assess the effectiveness of Gypsum as a chemical ameliorant on three selected salt-affected soils of the Ho-Keta plain, in the Volta region of Ghana.
Study Design: Complete Randomized Design.
Place and Duration of Study: Soil Research Institute, Kwadaso, Kumasi between June 2014 and July 2019.
Methodology: Soil sampling was taken in two forms. The initial sampling was taken at a depth of 0-30 cm from Anyako, Anyenui and Atiehife for the soil physical and chemical analysis. Samples were further taken from profiles, composited and sub-sampled for the leaching experiment. Approximately 2.6 kg of the soil samples from the different sites were taken, mixed thoroughly with different rates 0%, 25%, 50%, 75% and 100% of Gypsum, ($CaSO_4.2H_2O$) and filled into fifteen perforated polyvinyl plastic pots and replicated four times. The pots were saturated with water, incubated for 24 h and leached intermittently with 120 mL distilled water for a period of four weeks.

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Corresponding author: E-mail: louissackey12 @gmail.com, monniecando@yahoo.co.uk;

Results: Significant displacement of Na^+ by Ca^{2+} and subsequently leached became evident in the reduced values recorded for pH, EC and SAR. The applied gypsum reduced pH within a range of 4.0 to 4.2 compared to the original soil with no significant differences among the treatments at *p* = 0.05. Though a similar trend was observed for EC, significant difference at *p* = 0.05 was observed at gypsum level above 50%. Sodium adsorption ratio recorded a marked difference as gypsum level was varied with significant difference at *p* = 0.05 compare to the control.
Conclusion: The study revealed that gypsum rates at 75% and 100% Gypsum requirement were effective in improving the chemical properties of the soils with significant reductions in salinity, sodicity and pH. Atiehife soil performed better compared to Anyenui and Anyako soils.

Keywords: Degraded; leaching; saline-sodic; saline; toxicity; ameliorant; reclamation.

1. INTRODUCTION

The accumulation of excess exchangeable sodium in soils significantly cause repulsion and dispersion of clay particles and ultimately affect permeability [1] this further reduces soil productivity and threaten the sustainability of the agricultural system.

The adoption of chemical ameliorant such as Gypsum in the reclamation of salt-affected soil is most efficient and economical when the nature of the soil is either sodic or saline-sodic. This is because the procedure involves the displacement and leaching of replaced sodium beyond the root zone with adequate amount of water to avoid resodification, unlike saline soils which requires flushing only with water [2,3,4].

Studies on the effect of Gypsum application on saline-sodic soil reclamation have confirmed that Gypsum applied at higher rate to the soil removes the greatest amount of Na^+ from the soil columns and causes pronounced decrease in soil electrical conductivity (EC) and sodicity (SAR) [5]. Similar research in a study to evaluate the effects of gypsum addition to irrigation water on physical and chemical properties of soils with different levels of salinity and sodicity, showed that when soil is leached with gypsum saturated water, the amounts of exchangeable calcium and potassium increases. Also, soil pH decreases compared to the original soil, leading to a reduction in electrical conductivity and exchangeable sodium [6].

Approximately 318,000 ha of arable land in the Ho-Keta plains of Ghana is affected by varying degree of salinity [7]. This invariably, has affected the livelihood of the farming communities on the plain with an increasing effect on rural poverty and rural urban migration.

In spite of these challenges, no such study has been undertaken on the large scale salt-affected land of the Ho-Keta plain in the Volta region of Ghana.

The objective of the study was to assess the efficiency of Gypsum as a soil chemical ameliorant on three salt –affected soils in the Ho-Keta plains in the Volta region.

2. MATERIALS AND METHODS

The site and soil description of the selected areas had previously been discussed by Sackey, et al. [8].

2.1 Soil Sampling and Analysis

The soils were selected using previous soil survey reports of the area as a guide [9,10,11]. Two separate sampling was undertaken. Initial soil sampling was taken randomly at the depth of 0-30 from each of the three selected areas on the plain, namely Anyako, Anyenui and Atiehife. Further samples was taken from dug out, composited and sub-samples taken to represent each study area. The soils sampled were then packed into labeled polythene bags and transported to the CSIR-Soil Research Institute's laboratory, air-dried, gently broken up to pass through a 2 mm sieve and mixed thoroughly for soil analysis.

Soluble and exchangeable basic cations were determined before and after the experiment. Na^+ and K^+ were determined by flame photometry [12]; Ca^{2+} and Mg^{2+} by titration method [12]. Analysis of pH and EC were done while SAR and ESP were determined by formula.

2.1.1 Leaching experiment

White powdery laboratory gypsum, containing about 98% $CaSO_4.2H_2O$ with 172.17 g molecular mass was used for the study.

The amount of Gypsum used to achieve the fraction of soil requirement were calculated by a modified formula by Ross and Shelly [13].

$$GR = Bd \times A \times D \times \left(ESP_a - ESP_f\right) \times CEC \times 8.6 \times 10^{-7} \tag{1}$$

as treatments at different Gypsum rates; Control (T_0), T_1, T_2, T_3 and T_4 (applied at the rate of 0, 25, 50, 75 and 100%) of Gypsum requirement (GR) respectively, in order to reduce the actual exchangeable sodium percentage (ESP_a) of the salt-affected soils reported in Sackey, et al. [8] to a final critical exchangeable sodium percentage (ESP_f) of 5%

Where, GR, is the amount of Gypsum required, to amend a stipulated volume of soil. Bd, is the bulk density of soils (kg/m^3) (Table 1). A, is the area (m^2) of the soil. D, is the depth of soil (m) in the pot. ESP_a, is the actual exchangeable sodium percentage of the soil, before the experiment [8], ESP_f, is the final critical exchangeable sodium percentage reduced by 5%. CEC is the cation exchange capacity reported by Sackey, et al. [8] ($cmol_c$ kg^{-1}) and 8.6×10^{-7} is the correction factor for the atomic mass of pure gypsum in mega grams.

An average Gypsum requirement (GR) of 5.19 g/kg of soil, equivalent to 100% was used as the optimum Gypsum requirement for Anyako, Anyenui and Atiehife soils. Where treatments T_0, T_1, T_2, T_3 and T_4 were equivalent to 0, 1.30, 2.60, 3.89 and 5.19 g/kg of soil respectively.

The dug out profile samples were mixed thoroughly with the calculated rates of Gypsum and compacted into the pots to conform to the soils bulk densities. An approximated weight of 2.6 kg of soil was obtained at treatment levels of 0, 3.38, 6.76, 10.11 and 13.49 g/pot respectively.

The individual pots, were flooded intermittently with distilled water and leached for a period of four weeks after 24 h incubation period.

2.2 Statistical Analysis

Data collected were subjected to Analysis of Variance (ANOVA) to determine significant differences in main treatments and possible interactions using GenStat 12th Edition. Treatment means were separated using Least Significant Difference (Duncan Multiple Range Test) test at 5% level of significance.

3. RESULTS AND DISCUSSION

The pH of the soils reported by Sackey, et al. [8] decreased further within a range of 4.0 to 4.2. Fig. 1. Atiehife soil recorded the highest reduction in the levels of soil pH, compared to Anyako and Anyenui soils. Though the application of gypsum showed marked reduction in pH in all the samples no significant difference in the treatments was observed at $p = 0.05$.

The application of Gypsum to soils possibly cause an increase in the salt concentration as reported by Wong, et al. and Zia, et al. [14,15] but contribute further to reduce soil pH. The gradual reduction in pH could be attributed to the efficient displacement of exchangeable Na^+ and further leached out of the soil [16]. This mechanism reduced the hydrolysis of the clay colloids to form hydroxides, according to Ahmad, et al. [17].

The mean of soil pH in the control pots also decreased marginally. The observed trend however could be attributed to the swelling and dispersion of a sodium dominated soil colloid, as water was continuously added. This affected drainage, and enhanced an acidic anaerobic condition.

Generally, reduction in soil pH is partly attributed to the reclamation of salt-affected soils [18]. Atiehife soil recorded the highest level of salt reclamation as compared to Anyako and Anyenui soils.

Soil electrical conductivity of the soil [8], decreased within a range of 3.43 to 3.36 dS/m (Table 2). Meanwhile, there was no significant differences observed among treatments at lower level of application. However, significant differences became obvious at treatment level above 50% at $p = 0.05$. Soil electrical conductivity indicate the concentration of soluble salt in soil solution. High levels of salinity (EC) enhance soil-water osmotic effect and often cause physiological drought if it exceeds the crops critical limit [19].

Regular leaching of the displaced sodium and salt, reduced the salinity level significantly. The observed trend is consistent with the report by Chawla and Abrol [20].

The sodium adsorption ratio (SAR) of the selected soils [8], decreased significantly to values within a range of 5.87 to 4.12 (Fig. 2), with observed significant difference at p = 0.05 as

treatment level increased compared to the control.

The concentrations of soluble Ca^{2+} and Mg^{2+} ions before amendment changed from a range of (44.50-63.75) mmolL^{-1} and (13.00-51.50) mmolL^{-1} (Table 1) to a range of (37.31-61.26) mmolL-1 and (11.48–49.26) mmolL^{-1} (Table 2) respectively while the concentrations of soluble Na^+ and K^+ ions decreased from a range of (246.00 and 325.50) mmolL^{-1} to (107.10 and 27.70) mmolL^{-1} and (84.80 and 71.95) mmolL^{-1} (Table 1) to (5.56 and 2.27) mmolL^{-1} (Table 2) respectively.

Sodium adsorption ratio (SAR) index, assesses the potential of excess exchangeable Na^+ to cause soil particle dispersion [21]. Reclamation process in soils affected by sodium and salt become obvious when SAR decrease to permissible limits (SAR< 13) [18,22].

The trends observed, were probably due to increased concentration of Ca^{2+} in the soil solution to effect the displacement of adsorbed Na^+ and mg^{2+} and subsequently leached.

Replacement of sodium at the colloidal complex reduced calcium concentration in solution with time as reported by Suarez [23]. Marginal reduction in SAR in the control pots, may be due to disruption in equilibrium between divalent and monovalent cations within the solution and at the exchange sites with continuous addition of water in favour of divalent cations as reported by Reeve and Bower [24].
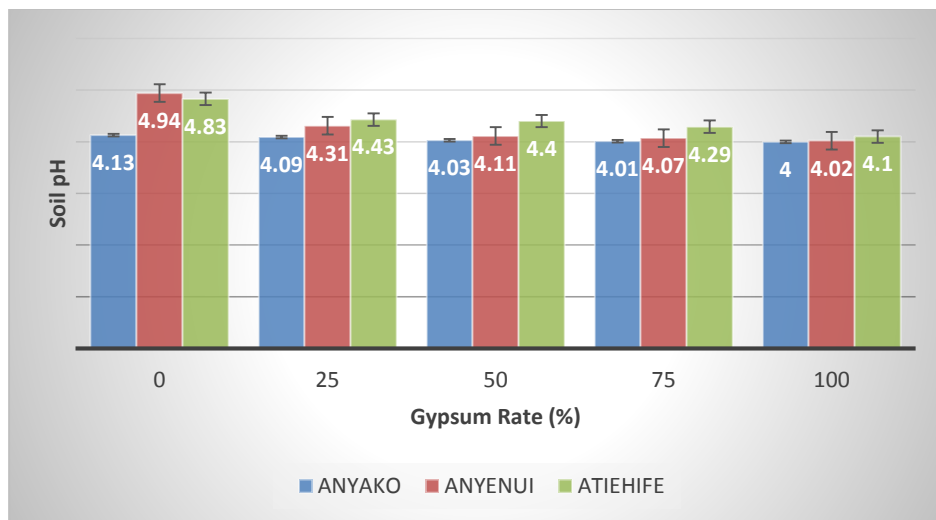

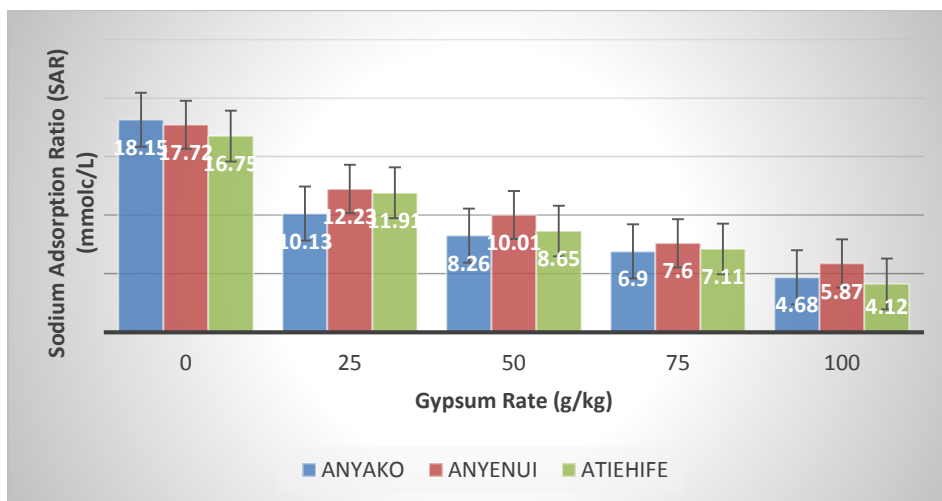**Fig. 1. The effect of different treatments (Gypsum rate) on the Soil pH**

Fig. 2. The effect of different treatments (Gypsum rate) on the sodium adsorption ratio

Table 1. Chemical composition of soils before amendment with gypsum

Soil	Bulk density	Soluble Ca	Soluble Mg	Soluble Na	Soluble K
	kg m^{-3}	---------------------- mmol L^{-1} -----------------			
ANYAKO	1.44	44.50	18.25	245.85	84.80
ANYANUI	1.45	55.75	13.00	302.37	76.80
ATIEHIFE	1.39	63.75	51.50	325.50	71.95
mean	1.43	54.67	27.58	291.24	77.85

Table 2. Chemical composition of soil after amendment with gypsum

Soil	Gypsum rate (%)	ECDS m^{-1}	Soluble Ca	Soluble Mg	Soluble Na	Soluble K
			------------------------------- mmol L^{-1} -------------------------------			
ANYAKO	0	4.30	37.31	11.48	89.70	3.10
	25	4.12	58.40	34.01	68.80	4.26
	50	4.09	53.10	40.45	56.50	4.47
	75	3.99	47.89	47.89	49.30	3.05
	100	3.43	42.03	42.03	33.00	3.65
ANYENUI	0	4.21	45.17	12.72	96.00	4.40
	25	4.13	61.26	29.98	82.20	3.36
	50	4.04	56.48	33.79	67.20	3.03
	75	3.99	52.23	42.93	52.40	4.20
	100	3.36	44.80	49.26	40.30	5.56
ATIEHIFE	0	4.27	44.96	36.70	107.10	2.27
	25	4.11	56.39	25.73	76.00	3.11
	50	3.96	52.61	49.32	61.80	3.62
	75	3.75	49.62	53.66	51.10	4.75
	100	3.41	32.92	57.30	27.70	2.87
LSD (Soil)		0.108	1.851	2.318	7.060	1.005
LSD (Gypsum)		0.140	2.389	2.993	9.110	1.298
LSD (S × G)		0.242	4.139	5.184	15.790	2.248

4. CONCLUSION

Result obtained from the study revealed that Gypsum facilitated the displacement and leaching of sodium and salt while improving the chemical properties of the soils. It can be concluded that appropriate levels of Gypsum at (75% and 100% GR) significantly caused a reduction in salinity, sodicity and pH. of the selected soil. Atiehife soil however, performed betther compared to soils from Anyenui and Anyako.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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