PHYSICO-CHEMICAL PROPERTIES AND AGRONOMIC PERFORMANCE OF NERICA L19 RICE IN THREE SALT–AFFECTED SOILS AMENDED WITH GYPSUM

BY

LOUIS SACKEY
(10080778)

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DECLARATION

I do hereby declare that this thesis has been written by me and that it is the record of my own research work. It has not been presented for another degree elsewhere. Works of other researchers have been duly cited by references to the authors. All assistance received has also been acknowledged.

Sign: …………………….

Louis Sackey

(Student)

Sign: …………………….

Prof. E.Owusu- Bennoah

(Principal Supervisor)

Sign: …………………….

Dr. F. M. Tetteh

(Co-Supervisor)

DEDICATION

This work is affectionately and humbly dedicated to my caring mother Mrs Leticia Sackey, my wife, Miss Joana Tackie and children and to all those who took an interest and encouraged me in my academic pursuit.

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ABSTRACT

In Ghana approximately 318,000 ha of arable land in the Volta region is affected by salt and excess sodium. This aspect of chemical land degradation has adversely affected agricultural productivity in this part of the country. The application of gypsum ($CaS0_4$ ($2H_2O$)) to soils affected by salt is widely used because it is easy to apply, easy to acquire and economical. It is against this background that the physico-chemical properties and agronomic performance of NERICA L19 rice was investigated on three salt-affected soils amended with gypsum. Three profile pits were dug to a depth of 2.0 m from three different salt-affected sites namely Anyako, Anyenui and Atiehife at the Volta region. The soils were sampled and their morphological and physico-chemical properties analysed. Morphological description and classification showed that, the soils, were mainly clayey within the top soil with a high presence of pyrite, rusty root channels and yellowish brown mottles. Two of the soils from Anyako and Anyenui were classified as Oyebi and the other from Atiehife was classified as Ada series respectively.

The agronomic performance of NERICA L19 rice was determined in the greenhouse. The soils were treated with different rates of gypsum at 0, 25, 50, 75 and 100 %, respectively and incubated for three days. The soils were leached and planted to NERICA L19 rice which was replicated four times in a completely randomized design. Plant growth parameters such as plant height, number of tillers and number of leaves were recorded at weekly intervals for twenty eight days. At the end of 28 days after transplanting, the rice was harvested and the plant tissue composition as well as the soil chemical composition were determined. Results obtained, showed that EC, SAR and pH decreased as the levels of gypsum application increased compared to the original soils. This indication of soil reclamation, provided a favourable chemical soil condition and corrected nutrient imbalance to support rice growth. The plant tissue had increased concentration of calcium, magnesium, potassium and low level of sodium. Generally growth performance of the three soils observed followed the trend; Atiehifie >Anyenui > Anyako.

In conclusion, enhanced rice growth was attributed to the improvement in the chemical properties of the soil. The application of gypsum at the rate of 1.39×10^4, 1.40×10^4 and 1.35×10^4 kg/ha, was recommended for Anyako, Anyenui and Atiehifie soils respectively.

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CHAPTER ONE

1.0 INTRODUCTION

Soil degradation, caused by salinization is a major environmental constraint that has severe adverse effect on sustainable agricultural productivity in arid and semi-arid climatic regions. This phenominum is associated with marine or continental origin (Qadir et al., 2006, 2007; Aubert, 1983). Salt- affected soils are predominantly classified according to either chemical or morphological systems as being saline, saline-sodic or sodic. Saline soils contain high enough concentration of soluble salts, with a minimum limit of 4 dS/m electrical conductivity of the saturation extract at 25 This adversely affects plant growth while sodic soils, contain excess exchangeable sodium, low levels of soluble salt and have negative effect on crop production and yield. Saline-sodic soils, have high level of soluble salt and exchangeable sodium (Richards, 1954).

Based on the morphological classification of the soils, saline soils are solonchacks while sodic soils are Solonetz (Richards, 1954). The solonetzic soils cause considerable modification of the soil profile with respect to physical as well as chemical properties to effect swelling and dispersion of clay particles leading to soil surface crusting and hard setting (Shainberg and Letey, 1984; Sumner, 1993; Qadir and Schubert, 2000). These problems affect soil aeration, root penetration seedling emergence, runoff and erosion as well as tillage and sowing operations (Oster and Jayawardane, 1998).

Soils affected by salt, degrade further with changes in soil reaction (pH) and the concentration of ions present either in soil solution or at the soils exchangeable sites. These changes cause soil-water osmotic potential, ion-specific effects and imbalances in plant nutrition. The cumulative effect however, leads to adverse impact on the growth of plant roots, soil microbial activities, and ultimately on crop yield and productivity (Naidu and Rengasamy, 1993; Fortmeier and Schubert, 1995; Grattan and Grieve, 1999; Mengel and Kirkby, 2001).

Amelioration of salt-affected soils demand a requisite knowledge and understanding of the nature and dynamics of neutral soluble salts present, as well as their proper management. These soils can be amended either by the use of chemicals or by growing of crops that tolerate high salinity and sodicity conditions (bio-amelioration).

Unlike saline soils whereby amelioration depends on the flushing of water through the soil profile to remove excess soluble salts beyond the root zone, saline-sodic soils like sodic soils require the displacement of exchangeable sodium (Na^+) with calcium (Ca^{2+}) from the soils colloidal complex and leached either below the root zone or out of the soil profile in percolating water (Ilyas *et al.*, 1997). The fraction of salts removed from the top layer and their depth of displacement, determine the extent of amelioration which is largely controlled by the quantity of water flushed through the soil (Minhas *et al.*, 1987). The use of chemical amendment to ameliorate soil is a well-established technology. The direct source of calcium commonly used is calcium chloride ($CaCl_2.2H_2O$), mined gypsum ($CaSO_4.2H_2O$) and phosphogypsum (by-product in the manufacture of phosphorous fertilizers). Many studies have shown that, the application of a soluble calcium amendment, combined with good drainage and tillage can reduce the harmful effect of high sodium content and reclaim sodic soils (Rasmussen *et al.*, 1972; Sharma *et al.*, 1974; Shainberg *et al.*, 1982).

Among the chemical ameliorants, agricultural gypsum is often used primarily because it is comparatively cheap, readily available, and easy to apply (Shainberg *et al.*, 1989). It has comparatively low solubility and requires time and water more than the other amendments (Overstreet *et al.*, 1951). Research, has shown that high rates of gypsum application on saline-sodic soils effectively displace and remove excess sodium out of the soil profile and cause great reduction in soil electrical conductivity (EC) and sodium adsorption ratio (SAR) (Hamza and Anderson, 2003). In addition to the use of gypsum to help reduce dispersion of clay particles, surface crust formation and slow rate of surface drying (Norton *et al.*, 1993; Norton and Rhoton, 2007), it has agricultural uses as well. It contributes to the improvement of soil aggregation, which in turn decreases bulk density (Webster and Nyborg, 1986). High application of gypsum to sodic soils increases water infiltration and reduces surface runoff and erosion (Keren *et al.*, 1983; Morin and Van Winkel, 1996) and also increases soil pH in aluminum dominated soils. With over dependence on chemical amendment by industry and reduction or removal of subsidy by the government of Ghana to farmers, the cost of chemical amendments has increased.

Salt tolerant crops alternatively, can be used for amelioration in calcareous sodic soils if good irrigation water and drainage are adequate. Through the activity of plant rooting system these crops increase the dissolution of calcite and liberate adequate levels of Ca^{2+} in soil solution to replace exchangeable Na^{+}. This mechanism of salt removal by crops contribute significantly to the phytoremediation process when harvested plant parts are not incorporated back into the soil (Qadir *et al*., 2005; Qadir and Oster, 2002; Robbins, 1986).

Salinity is one of the oldest and most serious environmental problems in the world (Mc-William, 1986) that can contribute to the poor growth of rice on salt affected soils. However, because reclamation of salt-affected soils lasts long, selection of a salt tolerant crop species is one of the possible means for overcoming the challenges of salt-affected soils. Rice plant, with the capability to regulate the effect of osmotic stress reduce water loss and increase water uptake. This mechanism minimixes the harmful effect of ionic Na^{+} stress by exclusion of Na^{+} from the leave tissue and stored in the vacuoles. (Blumwald, 2000; Munns et al., 2008.)

For effective utilization and management of salt affected soils, rice (*Oryza sativa* L.) is usually recommended for cultivation during reclamation of salt-affected soils because it is a moderately salt tolerant crop (Hassan *et al.*, 2001). Rice, being a staple food crop is categorized as one of the five main carbohydrate crops responsible for feeding the world's population, most importantly in African countries where the study area is no exception. It is known to support more than 3 billion people, and provide 50-80 % of their daily caloric intake (Khush, 2005).

New Rice for Africa variety (NERICA L19) rice was adopted for the purpose of this study. Generally, NERICA L19 rice is a cross bred between an *Oryza sativa japonica* variety (WAB 56-104) and an African *Oryza glaberrima* variety (CG 14). It was developed by the African Rice centre (ARC) (2004) using the complex embryo rescue technique. The progeny of this two genetically different parents grow faster, yield more, resists drought and pests or can thrive in poor soils and also smoother weeds like its African parents (Jones *et al.*, 1997; Dingkuhn *et al.*, 1999b). It is, however, not known the performance of this variety in salt-affected soils amended with gypsum.

1.1 Problem Statement

The effect of salt on soils is one of the most important abiotic stress that limits crop production. Salinity in Ghana, is a natural phenomenon in the Ho-Keta Plain of the Volta region because of its closeness to the Gulf of Guinea with erratic rainfall pattern and long dry spell. It is possible this may account, on the average, for the low rice yield potential of 2.71 tons/hectare (MOFA, 2007).

Increasing population together with rapid urbanization in some coastal communities of the Volta region have compelled most farmers to vacate their arable lands to less productive marginal lands. Several interventions employed to increase rice productivity on these marginal lands by irrigation have rather worsened the problem through the creation of man-made saline-sodic soils. This has affected fertility and crop yield with increased salt toxicity and poor soil condition. Sustainable rice crop production has thus been a major concern, in the region since consumption of rice by the people constitute 65 % of their daily caloric intake.

1.2 Justification

In Ghana an estimated 318,000 ha of arable land in the Volta region have been rendered marginally unproductive due to natural accumulation of excess exchangeable sodium at the soil colloidal complex, or neutral soluble salts within the soil profile (FAO, 1988). Deterioration of these lands have affected farming and other economic activities in the region leading to migration of the youth to the cities for non-existing jobs. Very few studies, have been carried out on these saline/sodic soils to find appropriate remedial measures to improve the productivity of the soils. Adequate information on the physico- chemical properties of some of these soils are however, not available.

Despite the difficulties associated with the amelioration of salt-affected soils, these soils are valuable resource that cannot be neglected. Consequently, if the challenges of global food security are to be met, it is imperative that attempts are made to know more about the physico-chemical properties of the salt-affected soils of the Ho-Keta Plains of the Volta region so as to improve the agricultural productivity of the vast stretch of land which currently lies fallow.

1.3 Objectives

The study has two objectives;

1. To provide information on the physio-chemical properties of the soils.
2. To provide information on the agronomic performance of New Africa Rice L19 rice in the soils amended with gypsum.

1.4 Hypothesis

H_O: Amendment of saline soil with gypsum will not improve the growth and nutrient uptake of NERICA L19 rice

H_A: Amendment of saline soils with gypsum will improve the growth and nutrient uptake of NERICA L19 rice.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter is critically aimed at reviewing available literature to find out works that have been done in relation to amendment of salt-affected soils. The review also aims at bringing to light all relevant information in relation to the topic. It also involves identifying the gaps and how a suitable and appropriate approach can be taken to guide the implementation of the research. The review will be in two sections.

1. The origin and types of salt- affected soils

2. The Management of salt-affected soils

2.1 Origin of salts

Saline soils are characterized by the presence of excess salt on the soil surface, and in the root zone of plants. Chemical weathering of soil parent material, is a process governed mainly by hydration, solution, oxidation, hydrolysis, and carbonation. This process further, contribute to the disintegration of primary minerals which contain feldspar and amphiboles in the exposed area of the earth crust into soluble salt constituents. The soluble salts become exceedingly concentrated, as they are carried further away from their original humid source either by surface or underground streams to a much drier or relatively arid areas. The accumulated ions, predominantly sodium, in the presence of dissolved carbon dioxide form precipitated salt with carbonate and bicarbonate of low solubility (Aubert, 1983).

In addition to precipitation, further changes involving the constituents of water through the process of exchange adsorption and differential mobility increase the concentration of chloride and sodium ions in underground water and ultimately soils (Kovda, 1965).

Two main groups of salt-affected soil can be distinguished with regard to the nature, characteristics and plant growth relationships (Szabolcs, 1974). These are saline and sodic soils.

Saline soils contain sufficient neutral soluble salts to adversely affect the growth of most crop plants. Sodium chloride is often the dominant salt though, calcium and magnesium are present in sufficient amounts to meet the growing demand of plants. The sodium adsorption ratio of saline soils are usually high because the dominant soluble salt is mainly sodium chloride and sodium sulphate. But saline soils also contain appreciable quantities of chlorides and sulphates of calcium and magnesium.

Sodic soils contain excess sodium salts capable of alkaline hydrolysis, mainly carbonate and bicarbonate of sodium. It is often termed as ‘Alkali’.

These two main groups of salt-affected soils though, they differ in their chemical characteristics, geographical and geochemical distribution, as well as physical and biological properties, require different approaches for their reclamation and agricultural utilization. In nature sodium salts and neutral soluble salts do not absolutely occur separately, but the salts capable of alkaline hydrolysis usually exercise a dominant role on the soil-forming processes and therefore determine the soil properties.

Saline-sodic soils share an intermediary characteristics of both saline and sodic soils. Other categories of salt-affected soils in other parts of the world though, less extensive are acid sulphate soils and degraded sodic soils

2.1.1 Acid-sulphate soils

These are soils with soil reaction (pH) ranging below 3.5 to 4.0 within a depth of 50 cm. They occur potentially in tidal swamps where presence of high levels of pyrites produces strong sulpuric acid when oxidized after drainage or when sulphur compounds are reduced (Pons, 1973). Pyrite formation is associated with brackish and saline mangrove swamps connected by tidal creeks where accumulation of coastal sediments is slow. Acid sulphate soils are limited by iron and aluminum toxicities, high salinity and phosphorus deficiency.

2.1.2 Degraded sodic soils

Degraded sodic soils are formed as a result of leaching of soluble salts. Through this process dispersed clay and organic matter travel down the profile resulting in the formation of a dark extremely compact soil layer with a sharp defined upper surface which merges gradually into the subsoil with depth. The upper layer is often loose and porous with laminar structure and paler than the layer below due to loss of clay and possible deposition of silica. The advanced stage of these soils is often acidic in reaction as amorphous silica content increase.

Calcium solonetz or Magnesium solonetz are a sub category of salt-affected soils in different parts of the world depending on the dominance of a particular chemical constituent.

In Ghana 200,000 and 118,000 ha are Solonchaks and alkaline respectively (Szabolcs, 1989) while 70,000 and 600,000 ha are Arenosols and Solonetzs respectively (FAO, 2000). Solonchaks have cations of sodium or calcium-magnesium complex in combination with anions of chlorine or sulphur (Aubert, 1983).

2.2 Management of salt-affected soils

The best management option available for sustainable agricultural production on a constrained soil resource is the efficient use of economic resources. Several approaches are most often adopted to reclaim salt-affect soils. The prominent among them are chemical, biological and agronomic. The combined effect of these does not only increase efficiency but reduces reclamation time as well. The integrated use of gypsum and organic or inorganic manure improves soil structure and soil health as well as maximizes and sustains yield by ensuring efficient use of inputs (Swarp, 2004).

2.2.1 Gypsum

Gypsum is chemically $CaSO_4.2H_2O$ and is a white mineral that occurs extensively in natural deposits. It must be ground before it is applied to the soil. Gypsum is soluble in water. The extent of solubility is dependent on the chemical composition of the soil solution and the concentration of mineral elements such as carbonate and sulphate present. The natural material contains 23 % calcium and 18 % sulphur.

$$Na_2CO_3 + CaSO_4 \longrightarrow CaCO_3 + Na_2SO_4 \text{ (leached)}$$

Gypsum contributes to improvement in soil structure, aeration, and drainage. A change of soil properties resulting from the application of gypsum is believed to be attributed to the replacement of sodium (Na) by calcium (Ca) on the exchange sites of the clay size particles. Research indicates that high rate of magnesium on exchange sites can lead to reduced water infiltration and a potential for erosion.

The role of gypsum in salt leaching as a result of flocculation of the dispersed soil matrix and improved hydraulic conductivity was reported by Qadir *et al.*, (2002); Muhammad and Khattak

2011). According to the report, gypsum in conjunction with other amendments is effective in decreasing the electrical conductivity of salt-affected soils cultivated with rice under submerged condition where high leaching of soluble salts is achieved. Gypsum application is proven to decrease SAR of salt affected soils but its effect could be enhanced with application of organic amendments.

2.2.2 Gypsum as a Soil Amendment

The use of gypsum under certain conditions has been shown to be of value in reclaiming sodic soils. Excessive concentration of sodium on the exchange sites of clay particles causes these particles to disperse thereby clogging soil pores. This causes reduction in water infiltration, and root development to be restricted. The soil becomes compact and hard when dry. Direct application of calcium from gypsum displaces and replace sodium on the exchange complex. If there is enough water movement through the profile the displaced sodium can be leached beyond the root zone. Therefore, gypsum coupled with good internal drainage are both necessary to reclaim sodic soils. Shabaan *et al.*, (2013), in a field experiment conducted to explore the effects of gypsum, farmyard manure and commercial humic acid application on the amelioration of salt affected (saline- sodic) soil, reported that application of gypsum with or without farm yard manure and commercial humic acid caused a decrease in soil pH, electrical conductivity, and sodium adsorption ratio, but increased root length and paddy yield, showing a negative but significant correlation between root length and electrical conductivity. According to the report, soil pH was significantly affected by the interaction of gypsum, farm yard manure and humic acid at 0 to 15 cm soil depth, whereas for 15 to 30 cm soil depth the interaction was not significant. The highest decrease in pH was observed with 100 % soil gypsum requirement, 20 t/ha farm yard manure and 48 kg/ha humic acid compared to the control treatment. Soil pH decreased with increasing rates of gypsum, farm yard manure and humic acid.

Zaka *et al.* (2005), in a three year field experimental research to determine the effect of an integrated approach on grain yield of rice and wheat as well as their effect on soil physical properties in a saline sodic soil using gypsum at 100 % GR, farm yard manure at 25 t/ha and chiseling followed by leaching with irrigation water indicated that the combination of different reclamative approaches may not only increase the efficiency but also reduce the time of reclamation. According to the report electrical conductivity was reduced in all the treatments except control after growing of the first rice crop. SAR reduced to permissible levels after the third crop. The soil parameters in control treatment did not improve. The combination of gypsum + FYM + chiseling was more effective in improving the soil condition. Gypsum application proved the best treatment giving highest grain yield of rice and wheat. However, this treatment followed statistically similar results with gypsum + FYM. Combination of gypsum and chiseling remained inferior to gypsum alone or gypsum + FYM. The combination of all the three was not useful. The combination of gypsum + FYM + chiseling was more effective in improving the soil condition.

Muhammad and Khattak (2011), in their research reported that gypsum in conjunction with other amendments is effective in decreasing the electrical conductivity of salt-affected soils cultivated with rice under submerged condition where high level of soluble salt is achieved. Gypsum application is proven to decrease the SAR of salt-affected soils but its effect could be enhanced with the application of organic amendments

Mohamed and Abdel-Fattah (2012), performed a leaching experiment using the columns technique to evaluate the efficiency of gypsum, water hyacinth compost "WHC", rice straw compost "RSC" and their different combinations on reclamation of clay saline-sodic soils. Their report showed that all the amendments either, single or in combination reduced EC, pH, SAR, and ESP compared with control. The results showed that combined treatments were more efficient than single ones. Increasing the rate of gypsum used lead to reduction in salinity as well as sodicity. With regard to (WHC) and (RSC), the result observed indicated that, RSC relatively had greater effect in reducing EC, pH, SAR and ESP than WHC. This study suggests that application of gypsum combined with WHC or RSC enhanced reclamation and caused more decreases in salinity as well as sodicity:

Gharaibeh *et al.* (2011), in a study on reclamation of highly calcareous saline sodic soil using Atriplex halimus and by-product of gypsum reported that amelioration of a calcareous saline sodic soil can be efficiently achieved by growing crops which can tolerate high levels of salinity and sodicity (phytoremediation) without applying an amendment. The efficiency of phytoremediation on treatment was comparable with that of gypsum. Planting Atriplex halimus reduced soil ESP and EC considerably. According to their findings, application of gypsum or farm manure significantly decreased EC and SAR of soils and produced maximum grain and straw yields of wheat. Economically, cyclic use of treated water (TW) and canal water (CW) with farm manure (FM) and gypsum, proved reasonably good indicating that external direct or indirect source of Ca^{2+} is required for colonization of saline-sodic soils. The effect of external and internal source of Ca^{2+} is dependent on the soil type and length of time.

Ahmad *et al.* (2011), stated that biological, chemical and bio-chemical strategies have been tested in the past for reclamation of saline-sodic and sodic soils. However, their study tested the efficiency of two crop rotations (rice-wheat and Sesbania-wheat) alone or in combination with either gypsum ($CaSO_4.2H_2O$) or sulfuric acid (H_2SO_4) for ionic displacement from four saline-sodic soils. According to their report rice crop biomass decreased at a soil saturation extract electrical conductivity (EC) of 8 dS/ m, whereas wheat and Sesbania were influenced at a sodium adsorption ratio (SAR) of ≥ 40. Gypsum treatment helped the crops to flourish well at these EC and SAR levels. The infiltrated volume of water dropped with decrease in ECe: SAR ratio of soils and increased in crop biomass production. Crop rotation treatments alone helped to leach sodium (Na^+) and other ions successfully at SAR ≤ 21 but were less effective at SAR ≥ 40 at which point plant growth was also curtailed. Gypsum and H_2SO_4 treatments significantly contributed to the leaching of Na^+ and other ions with water at SAR ≥ 40 under both crop rotations. Hence, crops effectively reclaimed soil at low sodicity level, whereas at high SAR, chemical amendments are obligatory in order to reclaim soils.

Karien *et al.* (2008), 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, reported that when soil is leached with gypsum saturated water, the amounts of exchangeable calcium and potassium increases, whilst soil pH decreases compared to the original soil. Reduction in electrical conductivity, exchangeable sodium and exchangeable sodium percentage in both treatments were observed though one treatment was more effective than the other in leaching of soil sodium. No observable change with depth was recorded for electrical conductivity, calcium and pH. The conclusion was that addition of gypsum to irrigation water improved soil physical and chemical properties and should be considered as an alternative in the process of reclamation of saline-sodic and sodic soils.

Chi *et al.* (2012), reported that application of desulfurized gypsum at the rate of 100 % GR and 200 % gypsum requirement significantly increased the wet stability of macro-aggregates (> 0.25 mm), soil infiltration rate (IR) and saturated hydraulic conductivity (Ks) of saline-sodic soil.

According to the report improvement in soil physical properties promoted the leaching of Na^+ and soluble salts and resulted in significant decreases in soil salinity, sodicity and pH. With improved soil physical and chemical properties, marked increases in growth and yield of rice were observed in desulfurized gypsum treated soils. With respect to the amount of desulfurized gypsum added to saline-sodic soils, a safe level of salinity (EC 3.0 dS/m) for rice growth was achieved in the 200 % gypsum requirement treatment and the average EC value of 4.93 dS/m in root zone of 100 % gypsum requirement treatment may correspond to the 75 % relative yield of rice according to the relationship between soil salinity (EC) and yield potential of rice as discussed by Maas and Hoffman (1977); Ayers and Westcot (1989). Thus, desulfurized gypsum is an effective amendment as an external source of Ca^{2+} for reclamation of saline-sodic soils.

Verma and Abrol (1980 a, b), compared the effect of chemically equivalent quantities of gypsum and pyrite at five application rates on soil properties and yield of rice and wheat in a highly sodic soil. The pyrite used had 31 percent total sulphur and gypsum, 85 percent calcium sulphate. Results, showed that pyrite was only about one-fourth as effective as gypsum. This is apparently due to lack of complete oxidation of pyrite once incorporated in sodic soils of high pH

Starkey (1966), pointed out that the best pH ranges for the activity of some sulphur oxidizing microorganisms, such as T. *thiooxidans* and T. *ferrooxidans* were in the range 2.0 to 3.0 and 2.2 to 4.7 respectively. Since the pH of sodic soils is usually very high, it is doubtful if the oxidation of sulphur or pyrite will proceed sufficiently. In order to be as effective as soluble calcium compounds, all the sulphur must undergo oxidation to form sulphuric acid. In the experiment by Verma and Abrol (1980 a, b), the soil improvement in pyrite plots did not approach the improvement obtained in gypsum treated plots even three years after the amendments were applied. These results tend to show that the efficiency of sulphur compounds that must oxidize to produce sulphuric acid before they can replace adsorbed sodium is likely to be low in sodic soils due to their high pH.

In another field study on a highly sodic soil Milap Chand *et al.,* (1977), compared the performance of several amendments on the yield of barley grown in a highly sodic soil. Their data showed that gypsum, sulphuric acid and aluminium sulphate were nearly equally effective in improving the yield of barley. As expected, farmyard manure or press mud (C) from the sugar factories adopting the carbonation process had little beneficial effect and press mud (S) from factories adopting the sulphitation process increased the yield since it contained about 9.3 percent calcium sulphate and about 36 percent organic matter.

Fatemeh *et al.,* (2013), in a study demonstrated that the sodicity (pH and SAR) of the surface soil in gypsum plots remained significantly lower than that in non-gypsum plots through out the course of the experiment. However, at lower depth, the application of gypsum had no effect. When gypsum was applied, an increase was observed in EC values. Gypsum application at 100 % soil gypsum requirement significantly increased the yield of wheat as compared with gypsum application at 50 and 75 % soil gypsum requirement. Increase in yield by applying coarse gypsum was greater than that of the equivalent amount of fine gypsum. Amending the soil with gypsum resulted in increase in soil hydraulic conductivity over the un-amended soil treatment. The use of coarse gypsum had a more positive effect in enhancing soil hydraulic conductivity than fine gypsum. This observation may be attributed to the physical effect of the coarse particles of gypsum in soil rather than to its chemical effect. The improvement in soil conditions under gypsum treatments favourably affected wheat growth which reflected in increased plant density, fertile spikelet, and 1000-grainweight and increase in biomass and wheat yield. Chemical analysis of wheat leaf showed that gypsum application did not have any effects on Mn and Cu concentrations of wheat leaf. It increased leaf N, Ca, P, S, and K but decreased Na. In summary, the effect of gypsum on plants is demonstrated in three ways. (1) Increase in Ca build-up, (2) Elimination of Na toxicity and nutritional balance in plants (reduced Na: K and Na: Ca ratio), and (3) Enhanced clay flocculation. As compared to fine-grade gypsum, coarse-grade gypsum is a much more cost-effective material to be used for sodic soil reclamation in terms of processing and transportation. The report finally recommended coarse gypsum at the rate of 100 % gypsum requirement to reclaim sodic soil.

Sharma *et al.*, (1974), showed the effectiveness of gypsum in reducing the quantity of sodium in soil. Rates of gypsum were applied, and the soil was tilled to various depths. Tile had been placed at various spacings under the plots before gypsum application and tillage.The result was that the high rate of gypsum (27 tons/acre) was needed and tilled to 3 feet in depth, with tile spacing of 30 feet, significantly reduced sodium saturation, compared with the check. A gypsum rate of 10 tons/acre, shallower tillage or wider tile spacing all resulted in much less reduction in sodium. All three conditions had to be more intense to result in an improvement in soil condition.

Yadav, (1973), presented a data on the effect of gypsum and sulphuric acid applied at 80 percent of the laboratory estimated gypsum requirements and in chemically equivalent quantities on crop yields in a highly sodic soil. The pH and ESP of the surface soil of the experimental field varied between 9.1 to 9.8 and 41 to 60, respectively. During the three years of study, crop yields were always higher in sulphuric acid than in the gypsum treated plots. There was also improvement in crop yields over the years which was apparently due to biological action of plant roots.

2.2.3 Role of manure as a buffer capacity of soils

Benefits of adding composted organic materials for remediation of salt-affected soils have long been recognized. Meyer and Sims (1979), in a report concluded that compost additions to soil, added organic compounds that bind soil particles together to improve structure, porosity, soil water retention, and oxygen supply

Pascual *et al.,* (1999), recommended that the addition of municipal solid waste compost, is a suitable technique for regeneration of sodic soil because it sustains soil quality for a long period. Smith *et al.,* (1987), in his contribution indicated, that organic matter addition improves soil quality by enhancing drainage in fine- textured soils, encourages robust root systems, reduce evaporation to sustain water and its efficient use for growing plants.

Dargan *et al.,* (1976), studied the effect of gypsum and farmyard manure singly and in combinations on the yield of berseem and a subsequent rice crop in a highly sodic soil. A strong interacting effect of gypsum and FYM on the yield of berseem appears, at least in part, due to the supply of micronutrients such as Zn, as observed by responses to the subsequent rice crop

Puttas Wamygowda and Pratt (1973), attributed the beneficial effect of straw incorporated in a sodic soil under submerged conditions to (i) the decomposition of organic matter, evolution of CO_2 and certain organic acids; (ii) lowering of pH and the release of cations by solubilization of $CaCO_3$ and other soil minerals thereby increasing the EC and (iii) replacement of exchageable Na by Ca and Mg and thereby lowering the exchangeable sodium percentage (ESP). Submerged anaerobic conditions were optimum for these processes according to these workers. Similar observations were made by Swarup, (1981). Further research by Gupta *et al.,* (1984) studied the effect of organic materials on the dispersion behaviour of soils and inferred that at high ESP, the role of organic matter in improving soil physical properties was somewhat questionable. However when applied in conjunction with inorganic amendments or when applied in soils of mild sodicity, organic materials have always proved beneficial and therefore their use in the reclamation of sodic soils occupies an important place. Research has confirmed that addition of manure to soils improves soil structural stability, increases soil hydraulic conductivity, increases cation exchange capacity and promotes higher nutrient levels. (Wichern et al., 2006; Oades, 1993; Kosmas and Moustakas, 1990; Hussian *et al.,* 2001; Von Lutzow et al., 2002; Jalali and Ranjbar, 2009).

2.2.4 Sulphuric acid as a soil amendment

Postulation by some workers indicate that sulphuric acid is more effective because calcium sulphate formed in situ as a result of its reaction with soil calcium carbonate is extreamely effective in neutralizing free sodium carbonate in soils and in replacing the adsorbed sodium. Miyamoto *et al.,* (1975) presented equations for predicting the changes in exchangeable sodium and dissolved salts results from known applications of sulphuric acid. Prather *et al.,* (1978) suggested that combining either calcium chloride or sulphuric acid with calcium sulphate as an amendment can appreciably shorten the time of reclamation and improve water efficiency as compared to calcium sulphate alone under certain soil conditions.

Large-scale use of sulphuric acid to improve sodic soils presents handling and application difficulties. The adoption of sulphuric acid in many parts of the USA for improving calcareous sodic soils is increasingly encouraging because its cost compared to gypsum is not prohibitive. It has been largely acknowledged however, that the yield returns of sulphuric acid amended soil is higher and cost effective. Similarly in USSR, a large-scale soil reclamation programme is being undertaken in the Arafaat Valley, in the Armenian Republic, by application of 1 percent sulphuric acid along with heavy leaching (Petrosian, 1977). However, gypsum is by far the most commonly used amendment because of its abundant availability and low cost.

2.2.5 Integrated Method

The adoption of an integrated approach using organic matter in conjunction with gypsum has widely been successful in reducing the adverse effect of excess sodium associated with sodic soils Vance *et al.,* (1998) found that the adoption of this integrated approach spontaneously reduced soil swelling and dispersion as well as salinity in surface soils more efficiently than with gypsum only.

Wong *et al.,* (2009), in support of this approach determined that the addition of organic material served as a source of food and energy to increase microbial population as well as to facilitate soil microbial decomposition while added gypsum provided a source of calcium and sulphur to reduce pH.

Chorum and Rengasamy, (1997) observed that an integrated application of gypsum and green manure to a highly sodic soil, resulted in a high reduction of soil pH relative to the addition of green manure or gypsum alone. Wong *et al.,* (2009), however, concluded that high increases in salinity as a consequence of gypsum application together with organic matter does not affect the presence of zymogenous micro-organism in degraded soils but rather rapidly increase their biomass to facilitate the decomposition process and even limit biomass substrate available.

Tejada *et al,* (2006), observed that, an integrated approach of compost and poultry manure application to a saline-sodic soil lead to a steady decline of salt and sodium content over a period of five years. The observed trend resulted in a marked increase in plant growth and soil porosity. Inference , made by (El-Shakweer *et al.,* 1998) to this approach indicated that compost and poultry manure gradually accelerated the displacement and subsequent removal of salt and excess sodium through leaching, leading to a reduction in salinity, water holding capacity and aggregate stability Avnimelech *et al.,* (1994) concluded that, the application of compost effectively dissolves precipitated calcium carbonate in a calcareous sodic soil to indirectly provide calcium to replace sodium from the exchange complex, to improve soil structure, water infiltration and reduce SAR. Pascual *et al.,* (1999) recommended that the addition of municipal solid waste compost, is a suitable technique for regeneration of sodic soil because it sustains soil quality for a long period. Smith *et al.,* (1987),in his contribution indicated that organic matter addition improves soil quality by enhancing drainage in fine- textured soils, encourages robust root systems, reduce evaporation to ensure water availability and water use efficiency for growing plants. Dargan *et al.,* (1976) studied the effect of gypsum and farmyard manure singly and in combinations on the yield of bersem and a subsequent rice crop in a highly sodic soil. A strong interacting effect of gypsum and FYM on the yield of bersem appears, at least in part, due to the supply of micronutrients such as Zn, as observed by responses to the subsequent rice crop.

2.2.6 Others

The use of by-products from industry has contributed to the cheap supply of acidic industrial waste materials which preferably can be used for sodic soil improvement. Press mud, a waste product from sugar factories, is commonly used for soil improvement. The constituents of Press mud (lime or gypsum) depends on the production procedure adopted. This explains whether the sugar factory uses carbonation or a sulphitation process for clarification of juice (Muhammad and Khattak 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site selection and description

3.1.1 Study Area

Two soil series in three salt-affected areas within the Lower Volta basin in the Ho-Keta Plain, were selected using previous soil survey reports of the area as a guide (Brammer, 1962; Asiamah, 1984, 1995). The selected areas included Anho district (Anyenui, and Atiehife) and Ketu district (Anyako). (Fig.3.1)

3.1.2 Site and soil description

Anyako has a poorly-drained saline-sodic soil which becomes flooded during the wet season. It occurs on a nearly level land where slope does not exceed 2 percent. The water table drops to about 1.3 m from the surface during the dry season. The second and third sites (Anyenui, and Atiehife) has poorly drained saline-sodic soils developed on illuvial deposits. The salt-affected soil at each area is essentially flat, and ponding water could occur during period of runoff. Depth of water table at Anyenui at the time of sampling was about 50 cm. Salt crusts was visible during sampling at Anyenui and Atiehife. The apparent source of excess water varied with each area but runoff water was common for all.

3.1.3 Soil sampling and preparation

The soil samples were collected from 0 to 30 cm depth respectively from the sampling sites with the aid of an earth chisel after the land surface had been cleared using a cutlass. In all, a total of three samples were taken from the three sites. An additional 400 kg of soil samples from 0 to 30 cm depth were collected from the three sites into sacks for the pot experiment. Profile pits were dug to a depth of 2.0 m from the three sites. The soils were sampled and their morphological and physico-chemical properties analysed. Morphological description was done according to the Guideline for Soil profile description (FAO, 1990).

The soils sampled were packed into labelled polythene bags and then put into another polythene bag to prevent contamination and transported to the laboratory. Soils were air-dried, crushed and sieved through a 2-mm sieve to get rid of stones, roots, twigs and other foreign materials. The sieved samples were stored at room temperature and followed by laboratory analysis.

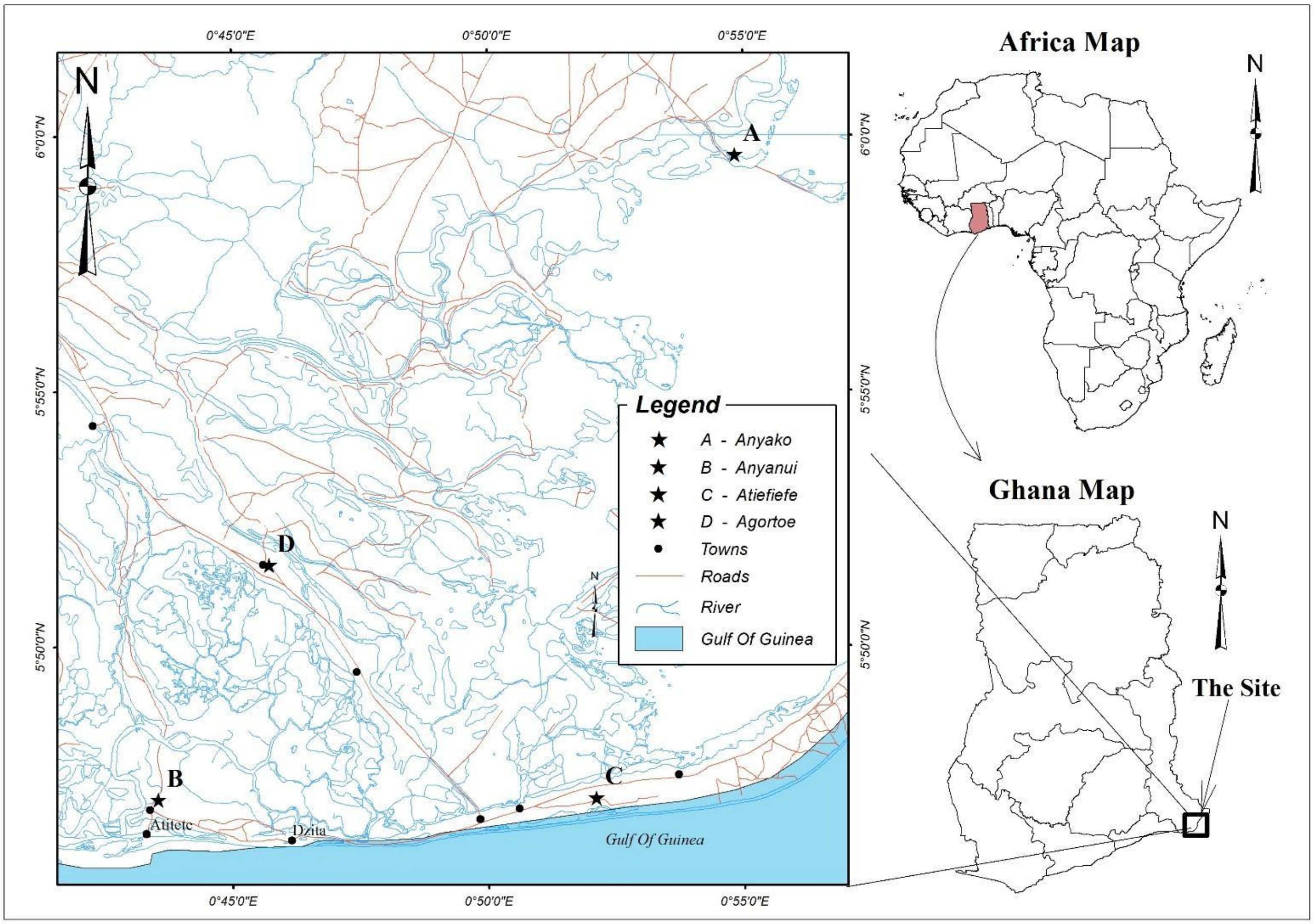

Fig. 3.1: Sampling sites at the Ho – Keta Plain of Ghana.

3.2 Soil physical properties

3.2.1 Particle size distribution

Soil particle size distribution was determined by the modified Bouyoucos, (1962) hydrometer method. Forty (40) g of soil was weighed into a beaker followed by the addition of 60 mL of 6 % H_2O_2 in order to destroy the organic matter in the soil. One hundred (100) mL of 5 % calgon (sodium hexametaphosphate) solution was added. The suspension was allowed to stand for approximately 10 min. and stirred with a mechanical stirrer for 30 min.

The suspension was then transferred into a graduated sedimentation cylinder using distilled water from a wash bottle and made up to the 1 liter mark with distilled water. The temperature of the suspension was recorded after equilibration. The content of the cylinder was then mixed thoroughly with the help of a plunger and hydrometer readings taken 5 min. and 5 h thereafter. The suspension was then poured into a 47-µm sieve and the particles retained on the sieve washed with water and dried in an oven at 105 °C for 24 h. The dried samples were then weighed to represent the sand fraction. Blank hydrometer readings without soil was taken. The particle size distribution was then determined using the formulae below;

$(\qquad) \quad \frac{\qquad}{\qquad}$ -- (3.1)

$(\quad) \quad \frac{\qquad}{\qquad}$ -- (3.2)

$Silt\ (\%) = ((1) - (2))$ -- - (3.3)

$(\quad) \quad \frac{(\ )}{(\ )}$ ----------------- (3.4)

3.2.2 Bulk density

Bulk density was determined using the core sample method by (Blake and Hartge, 1986). Core samples were taken from sampling location to represent the entire area. The soil surface was cleared and a core sampler was gently inserted into the soil with the help of a mallet. The soil surrounding the core sampler was then gently removed so that the sampler could be removed from the soil without disturbance. The ends of the sampler were levelled with a knife edge and covered. The sampled soils were then taken to the laboratory for bulk density determination.

In the laboratory, the content of the sampler was emptied into a clean moisture can with known weight (W_1). The moisture can together with its contents were oven dried for 72 h at 105˚C and thereafter, the weight was taken (W_2). Bulk density was calculated using the formula by Blake and Hartge, (1986).

$$(\qquad) \quad \frac{\qquad}{(\quad / \ )} \text{ --- } (3.5)$$

Where

= Bulk density of soil

M= mass of soil = W_2-W_1

W_2 = Weight in grams taken after oven drying the moisture can and its contents.

W_1 = Weight in grams of empty moisture can.

$\Pi d^2/4$= area of core

d= diameter of core

h= height of core

Π = constant=3.142

$(\Pi d^2/4)$ h= volume of core= volume of soil

3.3 Soil chemical properties

3.3.1 Soil pH

Soil pH was determined at soil to water ratio of 1:5 using (HANNA pH 211) pH glass electrometer. Five (5) g of soil sample was weighed into a 50 mL beaker and 25 mL of distilled water was added. The solid-liquid suspensions were allowed to stand overnight for salt to adequately dissolve and then stirred intermittently for 30 min. The suspensions were then allowed to equilibrate at room temperature. Using buffer solutions of pH 4.0 and 7.0, the pH electrometer was standardized. The standardized electrode was then inserted into the supernatant of the suspension to measure the pH of the soil sample.

3.3.2 Soil electrical conductivity

Soil electrical conductivity was determined at a soil to water ratio of 1:5 using (HANNA H19032) EC meter. Five (5) g of soil sample was weighed into a 50 mL beaker and 25 mL of distilled water was added. The solid-liquid suspensions were allowed to stand overnight and then stirred intermittently for 30 min. The suspensions were then allowed to equilibrate at room temperature. Using 0.1M KCl solution the electrometer was standardized. The standardized electrode was then inserted into the supernatant of the suspension to measure the EC of the soil samples.

3.3.3 Organic carbon in soil

The wet combustion method of Walkley and Black (1934) was used to determine the organic carbon content of the soil. Ten (10) ml of 0.167 M potassium dichromate ($K_2Cr_2O_7$) solution and 20 mL of concentrated sulphuric acid (H_2SO_4) were added to a 0.5 g soil which had been passed through a 0.5 mm sieve in an Erlenmeyer flask. The flask was then swirled to ensure full contact of the soil with the solution after which it was allowed to stand for 30 min. The unreduced $K_2Cr_2O_7$ remaining in solution after the oxidation of the oxidizable organic material in the soil sample was titrated with 0.2 M ferrous ammonium sulphate solution after adding 10 mL of orthophosphoric acid and 2 mL of barium diphenylamine sulphonate indicator from a dirty brown color to a bright green end point. Standardization of the $K_2Cr_2O_7$ with the ferrous ammonium sulphate was done and the amount of organic carbon calculated by subtracting the number of moles of unreduced K_2Cr_2O7 from the number of moles of $K_2Cr_2O_7$ present in the standardized titration.

The percent organic carbon was calculated as:

$$\frac{(\quad - \quad)}{\qquad\qquad} \qquad \text{---------------------------------} \; (3.6)$$

Where % C = Percent organic carbon

X = Titre value (mL)

M = Molarity of Fe $(NH_4)_2(SO_4)_2$

W = Weight of soil sample

3.3.4 Total nitrogen in soil

The modified Kjeldahl method ((Bremner, 1996) was used to determine total nitrogen. A 2 g of air dried soil was weighed into 250 mL Kjeldahl flasks and selenium catalyst and 5 mL of concentrated sulphuric acid were added. The mixture was then heated on a digestion block until the digest became clear. The digest was then allowed to cool and transferred with distilled water into a 50 mL volumetric flask and made up to volume. A 5 ml aliquot of the digest was taken into a Markham distillation apparatus and 5 mL of 40 % NaOH solution added. The liberated ammonia was collected into 5 mL of 2 % boric acid to which three drops of methyl red and methylene blue indicator mixture had been added. The distillate was back titrated against 0.01 M HCl to a purplish end point. The amount of total N was then calculated from the number of moles of HCl consumed in the titration reaction.

The percent N was calculated as follows:

$$\frac{\qquad\qquad}{(\ )\qquad\qquad(\quad)} \qquad\qquad (\quad)$$

Where 0.01 = Molarity of HCl

0.014 = Milliequivalence of Nitrogen

3.3.5 Available soil phosphorus and potassium

Available phosphorus and potassium was determined by Bray and Kurt (1945). Four (4) g of soil sample was weighed into an extraction bottle and 40 mL of extractant (0.03 M NH_4F in 0.025 M HCl) was added and shaken for about 2 min on a mechanical shaker. The soil-extractant mixture was filtered through a Whatman No.42 filter paper and divided into two parts. Ten (10) mL aliquot of the filtrate was put into a 50 mL volumetric flask and used to develop the colour. Phosphorus in the filtrate was determined using the molybdate-ascorbic acid method. The pH was adjusted by adding drops of p-nitro phenol indicator and few drops of 4 M NH_4OH until the solution turned yellow. The 2 mL of reagent B (1.056 g of ascorbic acid in 200 mL of reagent A) was added. Reagent A was made by dissolving 12 g of ammonium molybdate in 250 mL of distilled water plus 0.2998 g of antimony potassium tartarate to 1000 mL of 5 M H_2SO_4, mixed thoroughly and made up to 2 liter with distilled water. A blank was prepared using the fore mentioned procedure but without the soil. The spectrophotometer was calibrated using standard phosphorus solution by pipetting 5 mL of the standard phosphorus solution into a 50 mL volumetric flask, followed by colour development as outlined above. The intensity of colour at a wavelength of 712 nm was measured on the spectrophotometer and then recorded. Avaialable P was calculated using the relationship below:

$$(\qquad) \qquad \frac{(\qquad\qquad)\;(\qquad)}{} \text{-------------}$$

(3.8)

The remaining part was used to determine available potassium using the flame photometry.

3.3.6 Determination of carbonate

The percentage of carbonate in the soil sample was determined by the acidimetric method (Rowell, 1994). A 10 g of soil was weighed into a 100 mL flask and 20 mL of 2M HCl was added. The system was allowed to stand for a while to react and boil gently for 10 min. The suspension was filtered through a Whatman No 42 filter paper and washed with distilled water to 100 mL volume. A 10 mL aliquot of the filtrate was taken and titrated with 0.1M NaOH using 2 drops of phenolphthalein as indicator to give a pink end point.

$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$ -- (3.9)

$HCl + NaOH \longrightarrow NaCl + H_2O$ -- (3.10)

Calculation

1. Determine the number of moles of HCl that reacted with the carbonate in the soil sample (x).

2. Determine the initial amount of HCl added to the 10 g of soil (Y).

3. The amount of acid (HCl) that reacted with the carbonate (X-Y)
4. Amount of calcium carbonate ($CaCO_3$) that reacted

$(CO_3^{2-}) = ((X\text{-}Y) \times R)/ 2$ --- (3.11)

Where R =Mass of ($CaCO_3$) in the soil.

3.3.7 Determination of sulphate

The percentage of sulphate in the soil sample was determined by the turbidmetric method (Sheen et al., 1935). A 4 g of soil sample was weighed into a 100 mL extraction bottle and 20 mL of 10 mmol $CaCl_2$ added. The suspension was shaken for 1 h and filtered through a Whatman No 42 filter paper. A 1.0 g sample of $BaCl_2$ and 10 mL of solution (sodium acetate and acetic acid pH 7.0) were added concurrently.

The solution was poured into the absorption cell of the spectrophotometer and the turbidity measured at 440 nm

Calculation:

Mg/l (SO_4) = (X × dilution factor) / 0.001 -- (3.12)

3.3.8 Determination of Chloride

The percentage of chloride in the soil sample was determined by agentometric, method (Mohr, 1856). A 5 g of soil sample was weighed into a 100 mL beaker and 25 mL of distilled water added. About 5- 6 drops of potassium dichromate indicator were added and then titrated against a standard silver nitrate solution with continuous stirring until a brick- red end point.

Calculation.

Mg/l (Cl) = (A-B) × N× 35.45 ×1000)/ mL of sample---------------------------------- (3.13)

Where A = ml titration for sample

B = ml titration for blank

N = normality of $AgNO_3$

3.3.9 Determination of exchangeable bases

3.3.9.1 Extraction of exchangeable bases

A 5 g soil was weighed into an extraction bottle and a 50 mL solution of 1 M ammonium acetate (NH_4OAc. pH 7) was added. The bottle was shaken in a mechanical shaker for 1 h and the content filtered through a Whatman No. 42 filter paper into clean empty bottles. Exchangeable calcium and magnesium in the extract were determined using the EDTA method. Exchangeable Na and K were determined by flame photometry.

3.3.9.2 Determination of exchangeable Potassium (K)

The flame photometer was standardized such that 10 mg/kg of K gave 100 full scale deflections. The flame photometer after standardization was used to determine the concentration of potassium in 10 ml aliquot. The result was used in the calculation of the amount of potassium present in the soil as shown in the formula below.

$$(\quad / \quad) \quad \frac{}{\qquad\qquad\qquad} \qquad\qquad (\quad)$$

Where R = Flame Photometer reading for K (ppm)

39.1 = Molecular weight of Potassium

V = Volume of extract (100 ml)

3.3.9.3 Determination of exchangeable Sodium (Na)

The flame photometer was standardized in a way that 10 mg/kg of Na gave 100 full scale deflections. After the standardization of the photometer, the concentration of sodium in 10 mL aliquot was determined. The result was then used in the calculation of the amount of sodium (Na) present in the soil as shown by the formula below.

$$(\quad/\quad)\;\frac{\qquad\qquad}{}\qquad(\quad)$$

Where R = Flame photometer reading for Sodium (ppm)

V = Volume of extract (100 ml)

23 = Molecular weight of Sodium

3.3.9.4 Determination of exchangeable Calcium (Ca)

To a 10 ml aliquot of the sample solution, 10 ml of 10 % KOH and 1 ml triethanolamine (TEA) were added. Three drops of 1 M KCN solution and a few crystals of cal-red indicator were then added after which the mixture was titrated with 0.02 M EDTA solution from red to blue end point. The titre value was used in the calculation of calcium as shown below.

$$(\quad/\quad)\;\frac{\qquad\qquad\qquad(\qquad)}{}\;\text{..............}\;(3.16)$$

Where M = Molarity of EDTA

3.3.9.5 Determination of exchangeable Magnesium (Mg)

To a 10 ml aliquot of the sample solution, 5 ml of ammonium chloride – ammonium hydroxide buffer solution was added followed by 1 ml of triethanolamine. Three drops of 1 M KCN solution and a few drops of Eriochrome black T solutions were added after which the mixture was titrated with 0.02 M EDTA solution from red to blue end point. The end point titre value determines the amount of calcium and magnesium in the solution. The titre value of magnesium was then determined by subtracting the value obtained for calcium above from the new titre value obtained. The titre value of magnesium was then used for the calculation of the concentration of magnesium (Mg) as shown below.

$$(\quad/\quad)\qquad\frac{\qquad\qquad\qquad(\qquad)}{\qquad}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

(3.17)

Where M = Molarity of EDTA

Total exchangeable bases and percent base saturation were calculated using values obtained from the exchangeable bases.

3.3.9.6 Determination of Exchangeable acidity and Effective cation exchange capacity.

A 10 g of soil sample was weighed into a 100 mL extraction bottle and 50 mL of 1 M KCl solution was added. The bottle and its content were placed on a mechanical shaker and shaken for 30 min. The soil suspension was then filtered through a Whatman No. 42 filter paper into an empty clean bottle. Twenty five (25) mL aliquot was pipetted into a 100 mL conical flask and 2 drops of phenolphthalein indicator were added for titration to a permanent pink end point against 0.01 M NaOH. The titre value was recorded as titre for both H^+ and Al^{3+}. A 10 mL solution of

NaF was added to the solution at the endpoint and back titrated against 0.01M HCl until a colourless end point was reached. The titre was recorded as the titre for Al^{3+}.

The effective cation exchange capacity (ECEC) is equale to the sum of the exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, H^{+}, and Al^{3+} ((i.e.) $Ca^{2+} + Mg^{2+} + Na^{+} + K^{+} + H^{+} + Al^{3+}$)

3.3.9.7 Determination of Cation exchange capacity (CEC)

The soil cation exchange capacity (CEC) was determined by the ammonium distillation method (Richards, 1954). A 5 g soil was weighed into a leaching tube plugged with cotton wool and acid washed sea sand. A 100 mL solution of 1 M ammonium acetate (NH_4OAc. pH 7) was added. The leachate collected was then discarded. A 100 mL solution of ethanol was added to displace excess ammonium from the soil exchange sites. A 100 mL solution of 1.0 M sodium acetate was then added to the soil. Ten mL of the leachate was taken and 5 ml solution of sodium hydroxide was added and distilled in boric acid. The distillate was then titrated with 0.01 M HCl until a bluish end pointwas obtained.

Calculation.

CEC of soil = $(Y \times M \times W \times 100)/ V \times 1000$ -- (3.18)

Where Y = the titre value.

M = the Molarity of the HCl

W = the weight of nitrogen

V = the volume of the sample.

3.3.9.8 Determination of Soluble basic cations

A 20 g soil sample was weighed into an extraction bottle and 100 mL of distilled water was added. The bottle was shaken on a mechanical shaker for 1 h and the content filtered through a Whatman No. 42 filter paper into clean empty bottles. The concentration of soluble calcium and magnesium in the extract were determined using the EDTA method. The concentration of soluble Na and K were determined on a flame photometer after standardization.

3.4 Exchangeable sodium percentage (ESP)

Exchangeable sodium percentage (ESP) was calculated by using the equation below:

$$\frac{\quad}{\quad} \qquad (\quad)$$

3.4.1 Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) of the saturated extract was calculated from the equation 3.16 where the concentrations of soluble cations were expressed in mmol/L.

$$\frac{[\quad]}{\sqrt{\frac{[\quad]\;[\quad}{]}}} \qquad (\quad)$$

3.5 Gypsum requirement

White powdery laboratory gypsum, containing about 98 % $CaS0_4.2H_2O$ with 172.17 g molecular weight was used in the study because agricultural gypsum recommended for the experiment was not available on the market. The soil samples were treated once with five alternative levels:

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 respectively). The five (5) treatments were replicated four times. The amount of gypsum used to achieve the fraction of soil requirement was calculated by a modified formula where:

$$(\qquad) \qquad\qquad\qquad (\quad)$$

Source: http//www l .agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex166

GR, is the amount of gypsum required to amend a stipulated volume of soil in megagrams. Bd, is the bulk density of soil (kg/m^3). A, is the area (m^2) of the soil. D, is the depth of soil (m). $ESP_{a,}$ is the actual exchangeable sodium percentage of the soil, $ESP_{f,}$ is the critical exchangeable sodium percentage of 5.0. CEC is the cation exchange capacity ($cmol_c$ kg^{-1}) and 8.6×10^{-7} is the correction factor for the atomic mass of pure gypsum in megagrams. The actual exchangeable sodium percentage (ESP_a) of a salt-affected soil, should be reduced to the critical exchangeable sodium percentage (ESP_f) of 5 %.

For Anyako soil, 4.62 g of gypsum /kg of soil was required to reduce the actual ESP_a from 33.87 to 5.00

For Anyenui soil, 6.39 g of gypsum /kg of soil was required to reduce the actual ESP_a from 40.77 to 5.00

For Atiehife soil, 4.55 g of gypsum /kg of soil was required to reduce the actual ESP_a from 37.83 to 5.00

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 in the greenhouse experiment. 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). Polyvinyl plastic pots of 17.00 cm long and 15.00 cm internal diameter were used. Each pot was perforated with holes at the base to collect the leachate. The bottom of each pot was covered with filter paper to prevent loss of soil particles. Gypsum was mixed thoroughly with the soil samples before putting into the pots. To ensure uniformity, the soils were slightly compacted in order to achieve the soils field bulk densities. The pots were filled with approximately 2.6 kg weight of soil. Five pots were filled with the soil including control for each soil amendment, so that a total of sixty pots were available.

3.6 Greenhouse Experiment

NERICA L19 rice seeds were initially pre-germinated in rectangular seedling trays in a greenhouse. Twenty one day old seedlings were transplanted into the pots containing different rates of gypsum at 0, 3.38, 6.73, 10.09 and 13.49 g /pot. The five treatments were replicated four times and arranged in a completely randomized design. Nitrogen, phosphorus and potassium fertilizers were applied at the rate of 90 kg/ha as urea, 45 kg/ha as TSP and 45 kg/ha as muriate of potash equivalent to 0.34 N: 0.39 P: 0.16 K kg/pot. At the time of transplanting, half of nitrogen and all of P and K were applied to the pots. Further application of 45 kg N/ha was done two weeks after transplanting, as top dressing to each pot to ensure that nutrient supply was not limiting. After transplanting, an intermittent irrigation schedule was used such that at the end of each week 120 mL of water was added to the soil of each pot. This trend was adopted to ensure that the rate of water addition did not exceed the infiltration rate of the soil, and to satisfy the irrigation requirement of rice, while leaching of soluble salt from the pots was achieved.

Four weeks after transplanting, the plants were harvested by cutting the plant tops. The roots were carefully removed from the soil, washed to remove adhering soil particles and the fresh weight taken. The fresh weights of the leaves were also taken. The plant tops and the roots of each pot were oven-dried at 60 °C for 72 h and the dry matter taken. The samples were ashed at 550 °C, followed by dissolution in 2 M hydrochloric acid (HCl). The concentrations of Ca, Mg, K and Na as well as total nitrogen, phosphorus in the plant sample, were measured using different procedures and methods. Total N was measured by micro Kjeldhal's digestion method (Bremner and Mulvaney, 1982). Phosphorus concentration in the extract was determined using the molybdenum-blue procedure (Watanabe and Olsen, 1965). Concentrations of calcium (Ca) and magnesium (Mg) were determined by EDTA titration and that of sodium and potassium determined by flame photometry. Data on plant height, number of tillers, and number of leaves were taken from each plant one week after transplanting and continued at weekly intervals for a period of four weeks.

3.7 Soil sampling and analysis after experiment

Soil samples taken at the end of the experiment from each pot, was air-dried and passed through a 2 mm sieve. Soil samples were analysed for pH, EC and concentration of soluble basic cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} using 1:5 soil to water extract. The SAR of soil water extract was then calculated.

3.8 Data analysis

The experiment was conducted under completely randomized design and data collected for various parameters were analysed statistically by ‘analysis of variance’ technique. Duncan’s multiple range test (Steel and Torrie, 1980) was applied to determine the least significance difference at $p \leq 0{\cdot}05$, the Microsoft Excel package was used for plotting graphs.

CHAPTER FOUR

RESULTS

4.0 Introduction

This chapter presents results of the study in two sections. Section I: Shows the field profile description, morphological characteristics, classification, and the physico – chemical properties of the three soils. Section II: Shows the agronomic performance of NERICA L19 rice in the three soils amended with gypsum.

SECTION I

4.1 The field profile description, morphology characterization and classification of each of the soils.

The field profile description and morphological characterization of the soils are presented in Tables 4.1a to 4.1c.

Anyako soil, when seen in sections comprises of rusty root channels. The second and third horizons contain mottled dark yellowish (10 yr 4/6) clay with weak to moderate medium sub-angular blocky structure which also contains sticky slightly plastic presence of pyrites. The lower horizon is light olive brown (2.5 yr 5/4) and (2.5 yr 5/2) and brownish yellow (10 yr 5/8). It contains sand and has no definite structure. (Table 4.1a) The soil is classified as Oyebi series and Gleyic Solonetz respectively according to the Ghanaian and World Reference Base soil classification system (Brammer, 1956, 1962) and (ISSS/ISRIC/FAO, 1998).

The top soil of Anyenui is dark brown (10 yr 5/8), with massive clay texture. (Table 4.1b) It is crumbly with rusty root channels, cracks and deposits of salt crystals on the surface. The second horizon contains mottled olive yellow (2.5 yr 6/8) with silty clay and rusty root channels. The third horizon which is from 25 to 50 cm is grayish brown (2.5 yr 5/2) and contains mottles yellow (2.5 yr 8/8) and yellowish brown (10 yr 5/8). The water table starts from 50 cm and below. The soil is classified as Oyebi series and Gleyic Solonetz respectively, according to the Ghanaian and the World Reference Base soil classification system (Brammer 1956, 1962) and (ISSS/ISRIC/FAO, 1998).

As shown in Table 4.1c, the surface horizon of Atiehife soil is was very dark gray (2.5 yr 3/3) to light brown (2.5 yr 5/2). It has moderate to strong fine columnar structure, sticky slightly plastic with many fine roots and no definite structure. The second and third horizon is made of light yellowish brown (2.5 yr 6/3) and (2.5 yr 6/4) with mottles (10 yr 5/8) yellowish brown. The fourth and fifth horizon are also made of mottles (2.5 yr 5/8) with presence of pyrites. The last horizon is dark yellowish brown (10 yr 3/4) with brownish gray mottles (10 yr 6/2). The soil is classified as Ada series and Endogypsi-Gleyic Solonchak respectively, according to the Ghanaian and the World Reference Base soil classification system (Brammer 1956, 1962) and (ISSS/ISRIC/FAO, 1998)

Table 4.1a: Anyako soil profile description.

Horizon	Depth (cm)	Colour Matrix (Moist)	Texture	Structure	Consis-tency	Roots	Boundary	Special features
A	0 - 19	10 yr 3/6	scl	1,2 fcr	stkp	Many very fine	Gradual smooth	Rusty root channels
Bg1	19 – 49	10 yr 4/6	cl	1,2 msbk	stkp	Very few very fine	Clear smooth	Presence of pyrites
Bg2	49 – 61	2.5 yr 5/4	Cl	1 mfsbk	stkp	Very few fine	Clear smooth	Presence of pyrites
Cg1	61 – 81	2.5 yr 5/4	Sl	0	-	Few fine roots	Clear smooth	Presence of light olive mottles
Cg2	81 – 100	2.5 yr 5/2	sl	0	-	Fine roots	Clear smooth	Brownish yellow mottles present
2Cg3	100 – 130	10 yr 5/8	sl	0	-	Fine roots	Clear smooth	Brownish yellow and strong brown mottles

Texture: cl: clay loam, scl: sandy clay loam, sl: sandy loam,

Structure: 0: structureless, 1: weak, 2: moderate, f: fine, m: medium, sbk: subangular blocky,

Consistency : stk : sticky, p : plastic.

Table 4.1b: Anyenui soil profile description.

Horizon	Depth (cm)	Colour Matrix (moist)	Texture	Structure	Consistency	Roots	Boundary	Special features
A	0 - 10	10 yr 5/8	c	mCr	stkp	Many very fine and many fine	Clear smooth	Rusty root channels. Cracks on surface with salt crystals Rusty root channels
ACg	10 - 25	2.5 yr 6/8	sic	4 fi	stkp	Common very fine	Diffuse	Presence of olive yellow mottles
Cg	25 - 50	2.5 yr 5/2	sicl	4 fi	stkp	Very few very fine	Clear smooth	Presence of yellow and yellowish brown mottles
W	50^{+}							Water table starts

Texture: c: clay, sic: silty clay, sicl: silty clay loam

Structure: 4: massive, m: medium, fi: firm, stk: sticky, p: plastic, cr: crumbly

Table 4.1c: Atiehife soil profile description.

Horizon	Depth (cm)	Colour Matrix (Moist)	Texture	Structure	Consistency	Roots	Boundary	Special features
A	0-12	2.5 yr 3/1	sl	2,3fc0	stkp	Many very fine Very few fine root	Abrupt smooth	Presence of light brown mottles
ACg	12-22	2.5 yr 5/2	sl	0	stksp	Very few very fine	Clear smooth	Presence of yellowish brown mottles
Cg	22-45	2.5 yr 6/3	sl	0	stknp		Clear smooth	Presence of pyrite
Cg2	45-60	2.5 yr 5/8	sl	0	nstknp		Clear smooth	Presence of brownish gray mottles with presence of pyrite
Cg3	60-87	2.5 yr 6/2	sl	0	nstknp		Abrupt smooth	
2Cg	87-100	10 yr 3/4	scl	0	stknp		Abrupt smooth	

Texture: scl: sandy clay loam, sl: sandy loam.

Structure: 0: structureless, 2: moderate, 3: strong, f: fine,co: columnar, stk: sticky, s : slightly, n :non p: plastic,

4.2 Physical properties of the three soil profiles used for the study

The physical properties of the three soil profiles used for the study are presented in Tables 4.2a and 4.2b.

The texture of the soils varied for both the top and the sub soils. Sand content increased with a corresponding decrease in clay content with depth for Anyako while clay content increased with depth for Anyenui soil. Anyako had a depth of 42 cm thick clay loam sub soil underlain with 69 cm thick sandy loam textured soil. The top soil of Anyenui, varied between clay and silty- clay to a depth of 25 cm. This is underlain with silty clay loam textured soil to a depth of 5 cm. Atiehife is mainly sandy loam. Sand fraction in this profile increased from 68.02 to 79.04 % at a depth of 87 cm and it is underlain with 13 cm thick sandy clay loam soil. All the three sites, had varying textural pattern indicating the soils have different depositional regimes.

Table 4.2a: Physical properties of Anyako and Anyenui soil profiles used for the study.

HORIZON	DEPTH(cm)	SAND	CLAY	SILT	TEXTURE
		----------------------	(%)	------------------	
ANYAKO					
A	0 – 19	45.30	34.70	25.00	Sandy clay loam
Bg1	19 – 49	34.06	35.94	30.00	clay loam
Bg2	49 – 61	30.60	41.40	28.00	clay loam
Cg1	61 - 81	68.64	19.36	12.00	sandy loam
Cg2	81 - 100	55.62	16.38	28.00	sandy loam
2Cg3	100 – 130	63.98	16.02	18.00	sandy loam
ANYENUI					
A	0 – 10	18.76	45.24	36.00	clay
Acg	10 – 25	8.16	41.84	50.00	silty clay
Cg	25 - 50	18.60	37.40	44.00	silty clay loam

Table 4.2b: Physical property of Atiehife soil profile used for the study.

HORIZON	DEPTH(cm)	SAND	CLAY	SILT	TEXTURE
		-------------------------	(%)	------------------------	
ATIEHIFE					
A	0 – 12	68.02	17.98	14.00	sandy loam
Acg	12 – 22	71.50	10.50	18.00	sandy loam
Cg	22 – 45	72.32	9.68	18.00	sandy loam
Cg1	45 - 60	76.76	7.24	16.00	sandy loam
Cg2	60 - 87	79.04	2.96	18.00	sandy loam
Cg3	87 – 100	58.96	21.04	20.00	sandy clay loam

4.3 Chemical properties of the three soil profiles used for the study

Table 4.3a to 4.3f give the chemical properties of the three soil profiles used for the study

In this study soil pH was inconsistent from the top to the bottom horizon (Tables 4.3a and 4.3b). Soil pH in all the profiles ranged from strongly acidic to slightly acid (3.71 to 5.32). Soil pH in Anyako soil, decreased with depth from the A- horizon to the C- horizon, but increased at Cg1 and 2Cg3-horizons. In Anyenui soil, pH decreased within the A-horizon from 4.76 to 4.15 and increased to 4.57 in the Cg-horizon whereas in Atiehife soil, pH showed marked increase from 4.15 to 5.32 in the A-ACg-horizons but decreased within the C- horizon with depth. Soil pH decreased with increasing depths in all the horizons of the four profiles. However, there was no consistency in the trend.

Electrical conductivity values of the saturated extract (EC) decreased with increasing soil depth in all the three selected salt-affected soils. However, there were exceptional increases observed in the 2Cg3 and 2Cg-horizons of Anyako and Atiehife soils respectively. Atiehife soil, recorded the highest EC value of 6.27 dS/m. High EC values observed only in the top soils decreased with increase in depth as shown in Tables 4.3a and 4.3b. The electrical conductivity values for the top soils of Anyako, Ayenui and Atiehife soils were more than 4 dS/m but less than 8 dS/m.

Soil organic carbon content (Tables 4.3a and 4.3b) in the A-horizon of Anyako, Ayenui and the 2Cg-horizon of Atiehife soil were medium (1.65 %) to high (4.58 %), but low (0.09 %) to (0.95 %) in the remaining horizons. Reduction in organic carbon was observed with increasing depths in all the horizons of Anyako, Ayenui and Atiehife soils. However, there were exceptional increments in 2Cg3, and 2Cg-horizon of Anyako and Atiehife soils respectively. This could be attributed to the differences in their parental material with high accumulated organic carbon. The C-horizon recorded the lowest in organic carbon in all the four soils with the exception of 2Cg-horizon.

Total nitrogen content was low in all the profiles of the three salt-affected soils, and decreased with increasing depth. This is an indication of low organic matter and low mineralization as the soils were poorly-drained. (Tables 4.3a and 4.3b). However, Atiehife soil had the highest total nitrogen in the top soil 0.20 % compared to Anyako 0.15 % which recorded the least.

High levels of available K within a range of 132.8 to 264.1 mg/kg in the top soils of all the three salt-affected soils were observed. Though, there were decreases with corresponding increase within the profiles, the bottom profiles recorded high K values.

Available phosphorus decreased with increasing depth in all the profiles of Anyako Ayenui and Atiehife soils. However, there were exceptional increases in the Cg1-horizon of Anyako soil, Cg and 2Cg-horizons of Atiehife soil. The A-horizons of Anyako and Atiehife soils had high values of available P, with Atiehife soil recording the highest available P level of 2.79 mg/kg and Ayenui soil, recorded the least value of 0.98 mg/kg

In all the salt-affected soils, decrease in the trend of exchangeable cations with increase in depth was observed, although the trend was erratic (Tables 4.3c and 4.3d). The levels of exchangeable Ca^{2+} observed in all the soils were abnormally lower than that of exchangeable Mg^{2+}. Exchangeable Na^{+} comparatively was very high whilst exchangeable K^{+} was very low though, in the A-horizon of Anyako and Ayenui soils, exchangeable Mg^{2+} was higher than exchangeable Na^{+}. High values of exchangeable cation were recorded in the top soils, than the horizons below. Atiehife soil recorded the highest level of exchangeable cations followed by Anyako soil, with Ayenui soil recording the least.

Exchangeable acidity values showed inconsistent changes in Anyako, Anyenui and Atiehife soils. The trend in the values of exchangeable acidity in the three soils was in the order; Anyako > Ayenui > Atiehife. The highest acidity value of 1.74 $cmol_c$ /kg was recorded in Anyako soil and the least value of 0.3 $\mathrm{cmol_c/kg}$ recorded in Atiehife soil. Comparatively the values of exchangeable basic cations recorded in these soils were higher than the values of exchangeable acidity

The effective cation exchange capacity (ECEC) in Ayenui and Atiehife soils decreased with increasing depth but increased from 20.46 in Cg3-horizon to 38.29 $\mathrm{cmol_c/kg}$ in the 2Cg-horizon, whilst decrement in effective cation exchange capacity (ECEC) was erratic in Anyako soil (Table 4.3c and 4.3d). Effective cation exchange capacity (ECEC) ranged between 10.62 to 60.49 $\mathrm{cmol_c/kg}$.

Percent cation saturation followed an erratic trend in all the four soils from the top layer (A-horizons) to the horizons below Cg to Cg3-horizons. (Tables 4.3e and 4.3f). Percent Ca^{2+} saturation for the A-horizon decreased with depth in Anyako, Anyenui and Atiehife soils. Percent Ca^{2+} saturation ranged from a minimum of 7.34 to 31.53. Percent Mg^{2+} saturation decreased with increasing depth from A-Bg1 and A- ACg-horizons of Anyako soil with erratic trend in the remaining horizons. Percent Mg^{2+} saturation varied from 19.43 to 89.30. Percent Na^{+} saturation recorded the highest in all the horizons of Anyako, Anyenui and Atiehife soils (30.28 to 67.04). Percentage K^{+} saturation decreased with increasing depth in Anyenui soil, but the trend became inconsistent in the remaining horizons of Anyako, and Atiehife soils. Potassium saturation of ECEC recorded, ranged from 0.86 % to 9.01 %.

Percent base saturation decreased erratically with soil depth in all the three profiles. Base saturation ranged from 93.41 to 98.93 %, Atiehife soil had the highest, whilst Anyako soil had the least. (Tables 4.3e and 4.3f)

Table 4.3a: Chemical properties of Anyako and Anyenui soil profiles used for the study.

HORIZON	DEPTH(cm)	pH(H_2O)	EC(1:5) dS/m	Org.C	Org. Matter	N	Bray P	Av. K
				----------------- (%)		--------------	------------- (mg/kg)	--------
ANYAKO								
A	0 - 19	5.11	5.21	0.80	1.33	0.15	2.30	223.4
Bg1	19 - 49	4.37	4.51	0.34	0.59	0.14	0.98	226.2
Bg2	49 - 61	4.15	3.20	0.21	0.37	0.09	1.22	196.6
Cg1	61 - 81	4.53	2.86	0.16	0.27	0.07	2.10	98.9
Cg2	81 -100	4.31	2.77	0.19	0.34	0.08	0.96	86.6
2Cg3	100 -130	4.46	2.94	0.25	0.42	0.09	1.91	116.9
ANYENUI								
A	0 -10	4.76	5.63	2.91	5.01	0.18	0.98	260.9
ACg	10- 25	4.15	5.55	1.01	1.74	0.14	0.88	222.6
Cg	25 -30	4.57	3.54	0.55	0.95	0.09	0.48	199.9

Table 4.3b: Chemical property of Atiehife soil profile used for the study.

HORIZON	DEPTH(cm)	pH(H_2O)	EC(1:5) dS/m	Org. C	Org. Matter	N	Bray P	Av. K
				----------------- (%)		--------------	---------- (mg/kg)	--------
ATIEHIFE								
A	0 - 12	4.15	6.27	1.65	2.84	0.20	2.79	264.1
ACg	12- 22	5.32	5.21	0.31	0.53	0.12	1.40	200.5
Cg	22- 45	4.99	3.46	0.25	0.42	0.09	8.01	87.3
Cg2	45- 60	4.96	3.39	0.09	0.16	0.09	0.48	148.3
Cg3	60- 87	4.94	3.22	0.25	0.42	0.14	1.04	146.9
2Cg	87-100	3.91	3.70	2.15	3.70	0.10	7.89	234.5

Table 4.3c: Chemical properties of Anyako and Anyenui soil profiles used for the study.

HORIZON	DEPTH(cm)	Exch. Ca	Exch. Mg	Exch. Na	Exch. K	TEB	Exch. Acidity	ECEC
		(cmol$_C$/kg)						
ANYAKO								
A	0 - 19	4.01	13.08	8.27	1.03	26.39	0.92	27.31
Bg1	19 - 49	2.67	10.41	12.63	1.86	27.57	1.30	28.87
Bg2	49 - 61	3.47	10.94	9.28	0.98	24.67	1.74	26.41
Cg1	61 - 81	4.01	2.94	5.22	0.11	12.28	0.44	12.72
Cg2	81 - 100	2.67	2.94	4.35	0.14	10.10	0.52	10.62
2Cg3	100 - 130	2.67	5.87	5.22	0.41	14.17	0.62	14.79
ANYENUI								
A	0-10	2.67	11.21	10.88	2.50	27.26	0.50	27.76
ACg	10-25	1.86	11.61	9.75	1.18	24.40	0.94	25.34
Cg	25-30	2.67	8.54	8.70	0.31	20.22	0.50	20.72

Table 4.3d: Chemical property of Atiehife soil profile used for the study.

HORIZON	DEPTH(cm)	Exch. Ca	Exch. Mg	Exch. Na	Exch. K	TEB	Exch. Acidity	ECEC
		(cmol$_C$/kg)						
ATIEHIFE								
A	0 - 12	15.22	20.30	22.43	2.01	59.69	0.80	60.49
ACg	12- 22	2.40	5.43	18.73	1.08	27.64	0.30	27.94
Cg	22 - 45	2.40	6.94	8.27	0.78	18.39	0.36	18.75
Cg2	45 - 60	2.67	5.87	8.70	0.88	17.74	0.45	18.19
Cg3	60 - 87	2.67	8.27	8.22	0.98	20.14	0.32	20.46
2Cg	87 -100	3.47	14.69	16.85	1.86	36.87	1.42	38.29

Table 4.3e: Chemical properties of Anyako and Anyenui soil profiles used for the study.

HORIZON	DEPTH (cm)	Ca saturation	Mg saturation	Na saturation	K saturation	BS saturation
		----------	----------	(%)	----------	----------
ANYAKO						
A	0 - 19	14.68	47.89	30.28	3.77	96.63
Bg1	19 - 49	9.25	36.06	43.75	6.44	95.50
Bg2	49 - 61	13.14	41.42	35.14	3.71	93.41
Cg1	61- 81	31.53	23.11	41.04	0.86	96.54
Cg2	81-100	25.14	27.68	40.96	1.32	95.10
2Cg3	100 -130	18.05	39.69	35.29	2.77	95.81
ANYENUI						
A	0-10	9.62	40.38	39.19	9.01	98.20
ACg	10-25	7.34	45.82	38.48	4.66	96.29
Cg	25-30	12.89	41.22	41.99	1.50	97.59

Table 4.3f: Chemical property of Atiehife soil profile used for the study.

HORIZON	DEPTH (cm)	Ca saturation	Mg saturation	Na saturation	K saturation	BS saturation
		------------	------------	(%)	------------	------------
ATIEHIFE						
A	0 - 12	25.16	89.30	37.08	3.32	98.68
Acg	12 - 22	8.58	19.43	67.04	3.87	98.93
Cg	22 - 45	12.80	37.01	44.11	4.16	97.53
Cg1	45 - 60	14.68	32.27	49.04	4.84	97.53
Cg2	60 - 87	13.05	40.42	40.17	4.79	98.44
Cg3	87 – 100	9.06	38.37	44.01	4.86	96.29

4.4 Physico-Chemical properties of the three soils used before the pot experiment

The physico-chemical properties of the three soils used for the pot experiment are presented in Tables 4.4a and 4.4b

Bulk densities of the soils were high, an indication which suggest that the soils had high levels of exchangeable sodium and magnesium. The bulk density of the soils ranged between 1.40 to1.45 g/cm^3.

The pH of the soils were low. They ranged between 4.14 and 5.11 (Table 4.4a) Anyako soil recorded the lowest pH of 4.14 whilst Anyenui soil recorded the highest pH value of 5.11. The initial soil EC and SAR were high.

The Exchangeable sodium percentage within the productive layer of the soils (0 to 30 cm), were high for Anyenui, Atiehife, and Anyako soils (40.77, 37.82 and 33.37), (Table 4.4a). The original soil has low concentration of carbonate but high concentrations of sulphate and chloride.

Exchangeable magnesium and sodium were comparably higher than exchangeable calcium and exchangeable potassium. Exchangeable potassium recorded the least value compared to exchangeable calcium as shown in Table 4.4b. Cation exchange capacity recorded for all the soils were high. Ayenui soil recorded the highest value of 20.75 cmol$_c$/kg, whilst Atiehife soil recorded the least value of 16.10 cmol$_c$/kg.

The chemical properties of the soils within the productive zone showed that percent base saturation was high in all the soils though, Atiehife soil recorded the least value of 85.96 % (Table 4.4b). Base saturation ranged from 85.96 to 97.49 %. Anyenui soil recorded the highest. Sodium was the dominant cation among the soluble cations analysed as it was expected from the soils of arid and semi-arid regions (Table 4.4c). Soluble sodium recorded the highest value of 325.50 mmol/L in Atiehife soil while Anyako recorded the minimum value of 245.85 mmol/L.

Soluble potassium concentration in the soils was higher than soluble magnesium, while soluble magnesium concentration was higher than soluble calcium. The least soluble cation concentration of 13.00 mmol/L, was recorded in Ayenui soil.

Percent cation saturation was high for sodium than the other cations with potassium recording the least cation saturation. The highest sodium saturation recorded was 40.77 % for Ayenui soil while the least potassium saturation of 0.86 % was recorded in Anyako soil.

Table 4.4a: Physico-Chemical properties of the three soils used before the pot experiment.

SOIL	DEPTH (cm)	Bulk Density (g/dm^3)	pH (H_2O)	EC_e (dS/m)	SO_4^{2-}	CO_3^{2-}	Cl^-	ESP (%)	SAR $(mmol/L)^{0.5}$
					--------------- (mg/kg)		-----------		
Anyako	0-30	1.44	4.14	4.80	3.28	0.17	41.45	33.87	43.89
Anyanui	0-30	1.45	5.11	5.14	2.79	0.15	30.64	40.77	52.04
Ateihife	0-30	1.40	4.59	5.44	6.78	0.19	53.30	37.83	42.88

Table 4.4b: Chemical properties of the three soils used before the pot experiment.

SOIL	DEPTH(cm)	Exch. Ca	Exch. Mg	Exch. Na	Exch. K	CEC	% Base saturation
		--		----- ($cmol_c$/kg)	-------------------------------------		
Anyako	0-30	3.60	5.98	6.30	1.79	18.60	94.99
Anyenui	0-30	2.69	6.98	8.46	2.10	20.75	97.49
Ateihifie	0-30	2.30	3.83	6.09	1.62	16.10	85.96

Table 4.4c: Chemical properties of the three soils used before the pot experiment

Soil	DEPTH(cm)	Soluble Ca	Soluble Mg	Soluble Na	Soluble K	Ca saturation	Mg saturation	Na saturation	K saturation
		---------------------- (mmol/L) ----------------------				------------------------------- (%) -------------------------			
Anyako	0-30	18.25	44.50	245.85	84.80	19.35	32.15	33.87	9.62
Anyenui	0-30	13.00	55.75	305.16	76.80	12.96	33.64	40.77	10.12
Ateihifie	0-30	51.50	63.75	325.50	71.95	14.28	23.79	37.83	10.06

4.5 Chemcial properties of the three soils after harvest

The chemical properties of the three soils after harvesting of the treated crops is given in Table 4.5a and Figures 4.1 and 4.2

The mean of soil EC decreased from 3.92, 2.39 and 2.32 dS/m in the control treatment pots to 1.63, 0.99, and 0.5 dS/m in the gypsum treated pots, for Anyako, Anyenui and Atiehife soils respectively, indicating a significant difference at $p < 0.05$. Soluble calcium and magnesium level in Anyako soil, increased with increase in the treatments from an average minimum value of 22.92 and 37.93 mmol/L when no gypsum was applied to an average maximum value of 39.34 and 54.72 mmol/L when gypsum at 13.49 g/pot was applied respectively. Soluble sodium however, decreased with increase in the level of treatments from an average maximum value of 119.30 mmol/L in the gypsum free soil to an average minimum value of 53.25 mmol/L when gypsum at 13.49 g/pot was applied, while soluble potassium increased. Similar trend was observed in Anyenui and Atiehife soils respectively. There was no significant difference ($P < 0.05$) observed between the control treatment and gypsum applied at 3.38 g/pot in respect of soluble calcium and potassium in Anyako soil. However, there was significant difference at $P < 0.05$ observed for Anyenui and Atiehife soils.

The average soil pH decreased at the end of the experiment compared to the original soil as the level of treatments increased. A significant increase in pH was observed when gypsum at 3.38 g/pot was applied. Anyenui soil attained the maximum rise whereas Anyako soil attained the minimum compared to the control (Fig.4.1) Reduction in pH was subsequently observed in the higher level of gypsum applications at 6.73, 10.09, and 13.49 g/pot.

A marked decline in SAR upon the application of treatments was observed in all the soil types as compared to the control. Though the decline was steep in Anyenui soil at 3.38 g/pot of gypsum application, it recorded a higher SAR value compared to Atiehife soil which recorded the least at 3.38

g/pot of gypsum. Anyenui soil recorded the highest value followed by Anyako soil (Fig 4.2). There was not much difference in the decline in SAR for Anyako and Anyenui soils as compared to Atiehife soil which recorded the least SAR value when gypsum at 13.49 g/pot was applied.

Table 4.5: Chemical properties of the three soils used after harvest.

SOIL	Treatment	EC (dS/m)	Soluble Ca	Soluble Mg	Soluble	Soluble K
			(mmol/L)			
Anyako	T_0	3.92	22.92	37.93	119.30	2.41
	T_1	2.91	24.84	43.41	87.53	2.78
	T_2	1.87	31.34	49.54	78.66	3.21
	T_3	1.84	36.80	52.45	72.37	3.61
	T_4	1.63	39.34	54.72	53.25	5.68
	LSD (5%)	**0.021**	**2.786**	**1.668**	**1.776**	**0.779**
Anyenui	T_0	2.39	13.39	54.61	142.18	2.68
	T_1	2.03	17.00	61.08	86.77	4.13
	T_2	1.38	18.74	63.68	63.94	4.38
	T_3	1.18	20.75	65.26	56.47	6.42
	T_4	0.99	24.58	66.74	52.87	7.24
	LSD (5%)	**0.0171**	**1.764**	**1.805**	**4.900**	**0.343**
Ateihife	T_0	2.32	44.38	55.94	112.68	1.61
	T_1	0.80	47.35	61.02	86.51	2.02
	T_2	0.74	52.04	62.40	72.55	2.61
	T_3	0.68	53.52	64.80	61.29	2.91
	T_4	0.51	55.01	65.86	37.23	4.08
	LSD (5%)	**0.0218**	**1.694**	**1.891**	**5.516**	**0.157**

T_0 -T_4 represent gypsum applied at 0, 25, 50, 75 and 100 %

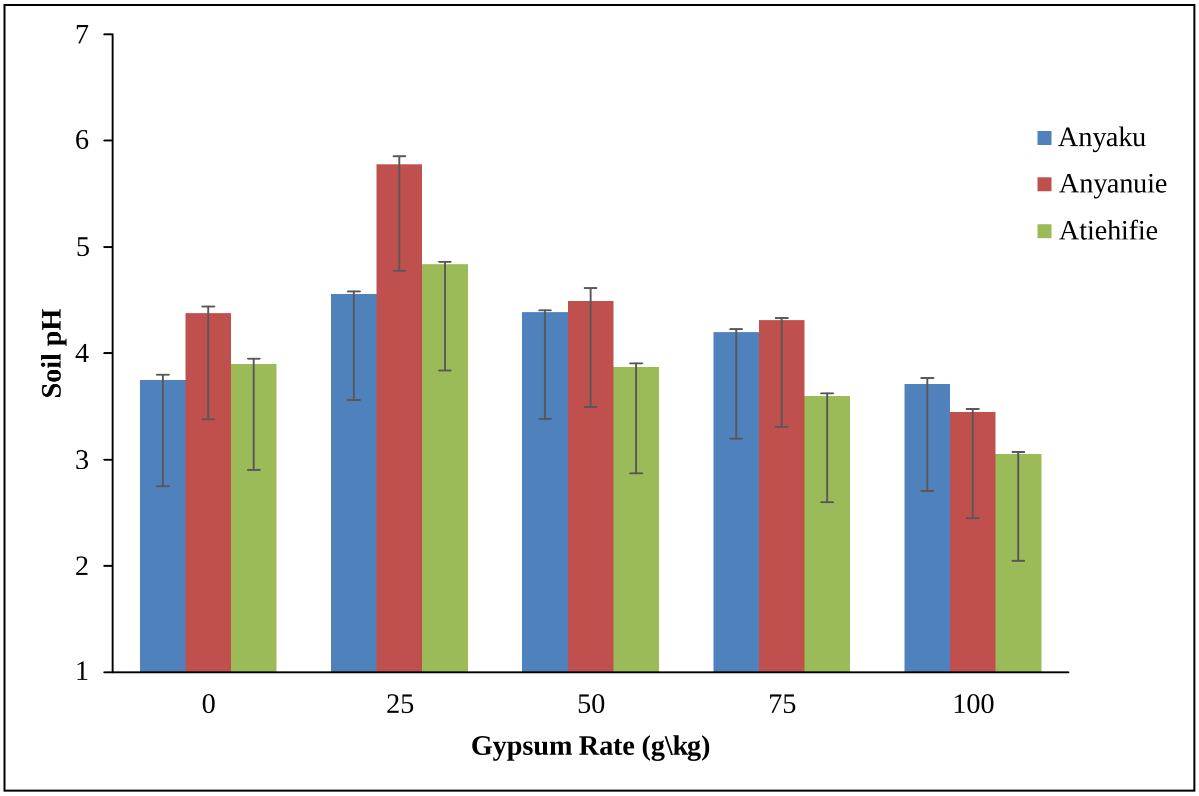

Fig. 4.1: The effect of different treatments (Gypsum rates) on the soil pH of the soils after crop harvest.

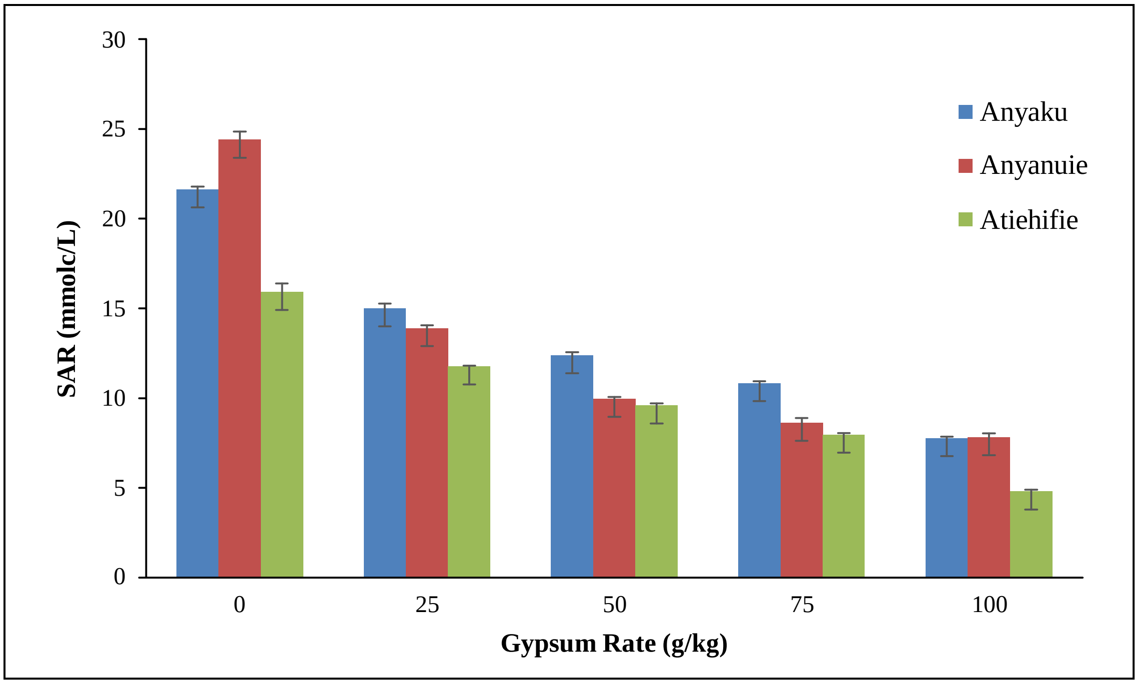

Fig. 4.2: The effect of different treatments (Gypsum rates) on the sodium adsorption ratio of the soils after crop harvest.

SECTION II

4.6 Growth parametres

The growth parameters of NERICA L19 rice are presented in Tables 4.6a to 4.6d.

In Anyako, Anyenui, and Atiehife soils, the number of leaves, tillers, and plant height, increased as the level of gypsum increased throughout week one, two, three and four.

The average number of leaves of the rice plant were fairly the same in all the soils in week one (Table 4.6a) However, differences in the pattern of leaf growth became significant ($P < 0.05$) as the treatment and period were varied. Growth in leaf numbers showed that Atiehife > Anyenui > Anyako.

The pattern of tiller growth was similar to that of the number of leaves (Table 4.6b). The number of tillers recorded for Atiehife soil was higher than that of Ayenui and Anyako soils respectively. However, there was no significant difference ($P < 0.05$) in tiller number observed between gypsum application at 3.38 g/pot and the remaining higher level of treatment in Anyako, Anyenui, and Atiehife soils.

The average plant height was fairly the same at the end of the first week (Table 4.6c). The effect of the treatments became significant ($P < 0.05$) as the period progressed. The measure of growth, in height was similar to the number of leaves and tillers. The trend however, was not different; Aitehife > Anyenui > Anyako.

The fresh and dry weights of the shoot and root of NERICA L19 rice for each of the soils increased with increase in the level of treatment. However, the increase was not significant at $P < 0.05$ between the control treatment and gypsum applied at 3.38 g/pot for Anyako and Anyenui soil but not Atiehife soil. The total dry biomass weight also increased as the level of treatment increased for each soil. There was no significant difference ($P < 0.05$) between the control and gypsum applied at 3.38 g /pot in Anyako and Anyenui soils whereas the difference became significant ($P < 0.05$) in Atiehife soil. The treatments however, became significant at $P < 0.05$ at the higher level of gypsum application in the three soils.

Total fresh biomass weight of harvested rice recorded for each of the soils, increased at different rates of gypsum (Table 4.6d). NERICA L19 rice performed better when gypsum at 13.49 g/pot, was applied, with a total fresh biomass weight of 24.9 g/kg of soil in Atiehife soil compared to Anyako soil which recorded a weight of 17.50 g/kg of soil. Growth pattern observed in Anyako, Anyenui and Atiehife soils indicate that though there was an increase in growth over the the control treatment, the difference was significant ($P < 0.05$) after gypsum at 6.73 g/pot was applied. A total biomass weight of 24.9, 23.64, and 19.62 g/kg of soil were attained at 13.49 g of gypsum respectively. Biomass weight decreased in the order; Atiehife > Anyenui > Anyako.

Table 4.6a: Effect of different treatments on the number of leaves of the rice plant with growth durations.

SOIL	TREATMENT	WEEK 1	WEEK 2	WEEK 3	WEEK 4
Anyako	T_0	6.00	8.25	14.25	20.25
	T_1	7.25	12.50	19.75	27.50
	T_2	8.75	16.00	26.00	33.50
	T_3	7.00	18.50	26.50	36.25
	T_4	7.00	20.00	31.75	43.00
	LSD (5%)	**2.319**	**4.416**	**4.625**	**6.047**
Anyanui	T_0	7.00	9.75	15.50	26.25
	T_1	8.50	16.50	24.50	37.25
	T_2	9.50	18.75	31.50	44.00
	T_3	8.50	20.25	33.00	45.25
	T_4	9.00	22.00	35.00	47.00
	LSD (5%)	**2.235**	**2.031**	**4.999**	**6.491**
Ateihifie	T_0	6.50	10.00	18.75	27.25
	T_1	8.00	17.00	30.25	42.25
	T_2	8.25	18.50	36.00	48.75
	T_3	8.75	21.75	38.50	50.75
	T_4	9.50	23.75	43.25	59.25
	LSD (5%)	**1.804**	**3.783**	**4.942**	**7.760**

T_0-T_4 represent gypsum applied at 0, 25, 50, 75 and 100 %

Table 4.6b: Effect of different treatments on the number of tillers of the rice plant with growth duration.

SOIL	TREATMENT	WEEK1	WEEK2	WEEK3	WEEK4
Anyako	T_0	1.00	3.00	4.75	6.25
	T_1	0.50	5.25	7.00	8.25
	T_2	1.00	7.25	9.25	10.75
	T_3	0.25	9.25	11.25	13.00
	T_4	0.75	11.00	12.50	14.50
	LSD (5%)	**0.615**	**1.469**	**1.417**	**2.499**
Anyanui	T_0	0.75	3.00	4.75	6.75
	T_1	0.75	5.75	7.75	10.25
	T_2	1.50	8.00	10.00	12.00
	T_3	1.25	9.50	11.50	13.50
	T_4	1.50	11.25	13.25	15.25
	LSD (5%)	**1.246**	**1.261**	**1.794**	**2.175**
Ateihifie	T_0	0.75	3.25	6.00	7.75
	T_1	0.75	6.00	9.75	11.50
	T_2	1.25	7.75	11.00	13.25
	T_3	1.25	9.25	12.75	14.75
	T_4	1.50	11.25	14.50	17.25
	LSD (5%)	**0.953**	**1.696**	**2.218**	**1.906**

T_0-T_4 represent gypsum applied at 0, 25, 50, 75 and 100 %.

Table 4.6c: Effect of different treatments on the rice plant height with growth durations.

SOIL	TREATMENT	WEEK 1	WEEK 2	WEEK 3	WEEK 4
Anyako	T_0	37.90	42.18	48.55	53.75
	T_1	38.50	45.93	54.62	60.80
	T_2	46.32	52.67	59.95	63.23
	T_3	41.67	56.00	62.80	64.10
	T_4	41.08	61.50	67.82	69.55
	LSD (5%)	**7.14**	**5.05**	**4.53**	**4.57**
Anyenui	T_0	42.35	47.82	51.58	54.05
	T_1	44.35	53.12	57.25	59.00
	T_2	44.45	53.90	61.02	62.00
	T_3	43.23	57.50	62.65	64.23
	T_4	42.40	58.99	65.60	67.92
	LSD (5%)	**7.32**	**4.061**	**4.417**	**5.124**
Atiehife	T_0	43.70	51.13	57.03	63.07
	T_1	45.50	58.98	65.78	69.65
	T_2	45.00	60.73	68.33	70.45
	T_3	46.35	62.15	69.82	73.27
	T_4	47.62	65.75	71.55	75.25
	LSD (5%)	**8.21**	**3.34**	**4.16**	**4.14**

T_0-T_4 represent gypsum applied at 0, 25, 50, 75 and 100 %.

Table 4.6d: Effect of different treatments on rice plant biomass weight with growth duration.

SOIL	TREATMENT	FRW	FSW	DRW	DSW	DSW+DRW	FSW+FRW
		(g/kg of soil)					
Anyako	T_0	1.68	2.28	0.77	1.54	2.31	3.96
	T_1	2.65	3.68	1.30	2.29	3.59	6.33
	T_2	4.72	5.18	3.18	4.10	7.28	9.91
	T_3	6.65	6.66	5.08	5.76	10.84	13.31
	T_4	9.06	8.45	7.05	7.32	14.37	17.51
	LSD (5%)	**2.114**	**1.019**	**2.130**	**0.958**	**2.786**	**2.661**
Anyenui	T_0	1.52	2.98	0.67	1.80	2.47	4.50
	T_1	3.12	4.15	1.80	3.00	4.80	7.27
	T_2	5.39	5.69	3.79	4.48	8.27	11.08
	T_3	7.53	7.52	5.81	6.38	12.20	15.05
	T_4	10.18	9.45	8.00	8.06	16.06	19.63
	LSD (5%)	**2.241**	**1.638**	**2.209**	**1.502**	**2.196**	**2.376**
Ateihife	T_0	3.14	3.72	1.49	2.74	4.23	6.85
	T_1	6.52	5.29	4.69	4.06	8.75	11.81
	T_2	9.70	6.87	7.68	5.24	12.93	16.58
	T_3	12.00	8.68	9.84	7.51	17.35	20.68
	T_4	14.43	10.48	12.09	9.21	21.30	24.91
	LSD (5%)	**3.572**	**2.076**	**3.560**	**1.931**	**5.354**	**5.495**

T_0-T_4 represent gypsum applied at 0, 25, 50, 75 and 100 %. FRW; Fresh root weight, FSW; Fresh shoot weight, DRW; Dry root weight, DSW; Dry shoot weight.

4.7 Tissue Composition of NERICA L19 rice

The tissue composition of NERICA L19 rice is presented in Table 4.7a

The mean composition for calcium, potassium and phosphorus in NERICA L19 rice tissue consistently increased compared to magnesium as the applied rate of gypsum increased. However, the composition of sodium and nitrogen decreased in Anyako, Ayenui and Atiehife soils. The concentration of calcium, magnesium and potassium became increasingly significant at $P < 0.05$ after 6.73 g/pot of gypsum was applied in Anyako and Atiehife soils with non significance in Anyenui soil. A similar trend was observed, with decrease in the concentration of sodium. Magnesium concentration was not significant ($P < 0.05$) for all the treatment in Anyenui soil, as well as when gypsum was applied at 10.09 and 13.49 g/pot in Ayanko and Atiehife soils.

The concentration of nitrogen decreased while that of phosphorus increased as the level of treatment increased. However, the differences were not significant between the control treatment and gypsum applied at 3.38 g/pot in Anyako and Ayenui soils in respect of nitrogen, but became significant as the level increased. In respect of P accumulation, the differences were not significant in Anyako, Anyenui and Atiehife soils, but became significant in Anyako and Anyenui soils when gypsum was apllied at 13.49 g/pot.

Table 4.7a: Effect of different treatments on the tissue composition of NERICA L19 rice after harvest

SOIL	TREAT.	Ca	Mg	Na	K	N	P
		(%)					
Anyako	T_0	0.127	0.165	0.230	0.48	1.77	0.22
	T_1	0.177	0.202	0.190	0.56	1.72	0.23
	T_2	0.190	0.292	0.150	0.65	1.68	0.24
	T_3	0.195	0.190	0.117	0.67	1.51	0.27
	T_4	0.230	0.212	0.102	0.89	1.23	0.35
	LSD (5%)	**0.049**	**0.105**	**0.054**	**0.250**	**0.074**	**0.083**
Anyenui	T_0	0.140	0.157	0.222	0.51	1.88	0.14
	T_1	0.167	0.150	0.190	0.57	1.52	0.16
	T_2	0.192	0.165	0.145	0.71	1.51	0.16
	T_3	0.185	0.125	0.125	0.80	1.42	0.20
	T_4	0.210	0.132	0.100	0.92	1.28	0.30
	LSD (5%)	**0.030**	**0.04**	**0.066**	**0.123**	**0.059**	**0.103**
Ateihifie	T_0	0.145	0.122	0.170	0.83	1.52	0.21
	T_1	0.208	0.165	0.130	0.97	1.41	0.23
	T_2	0.268	0.200	0.117	1.07	1.40	0.24
	T_3	0.295	0.172	0.105	1.17	1.41	0.25
	T_4	0.537	0.155	0.090	1.28	1.20	0.25
	LSD (5%)	**0.078**	**0.041**	**0.101**	**0.243**	**0.114**	**0.017**

T_0-T_4 represent gypsum applied at 0, 25, 50, 75 and 100 %.

CHAPTER FIVE

DISCUSSION

5.0 Introduction

This chapter discusses the results obtained and make comparisons with reference to available published research works. The discussion would come out with conclusions and possible suggestions by way of recommendations for future studies on salt-affected soils.

5.1 Soil characteristics of the four soil profiles

5.1.1 Soil Textural characteristics

High clay fraction in soils favour accumulation of salt and sodium to cause soil deterioration (Qadir and Schubert, 2002). The textural characteristics of the selected soils, had high proportions of clay within the productive layer, with the exception of Atiehihfe soil, an indication of high accumulation of salt and sodium. The soils were mainly clay loam, silty clay, and sandy loam for Anyako, Anyenui and Atiehife soils respectively

5.1.2 Soil pH

Soil pH of salt-affected soil is normally high, due to increased concentration of basic cations and salt in soil solution of arid and semi- arid climatic regions (Abrol *et al*., 1988). Saline soils have pH values below 8.5, whilst saline-sodic or sodic soils have pH values of 8.5 and above (Dregne, 1976). However, this condition is not always permanent. The low soil pH levels in the selected soils could be attributed to the high level of sulphate and chloride than carbonates (Table 4.4a) (Harward and Reisenauer, 1966). The chemical constituent of the soils however, reduced the tendency for hydrolysis of Na_2CO_3 to liberate OH^- in soil solution resulting in the low pH (Janitzky *et al.*, 1964). The presence of pyrite, might as well contribute to the observed low levels in pH. This is because oxidation of pyrites after drainage and subsequent reduction after hydration generally produce hydrogen sulphide which hydrolyses into sulphuric acid to reduce soil pH (Evangelou, *et al.*, 1995). The resulting pH of the soil after drainage depends on the extent of pyrite oxidized and the quantity of acid neutralizing components present, such as silicates, carbonates and exchangeable bases (Hechanva, 2004).

5.1.3 Electrical conductivity

Accumulation of soluble salts in soils is a measure of its degree of salinity (Rietz and Haynes, 2003). High concentration of soluble salts increases the soil water osmotic potential and this has adverse consequences on plant growth and development (Ali. 2011). The degree of salinity, of the three soil samples was estimated based on soil salinity rating (Appendix 2). High ECvalues in the top soil was an indication of poor drainage. The electrical conductivity values for the top soils were more than 4 dS/m but less than 8 dS/m indicating that the soils were moderately saline.

5.1.4 Soil Organic Carbon

Soil organic carbon contributes to soil productivity, due to its ameliorative effect on nutrient supply, nutrient retention and the improvement in soil structure formation (Glaser *et al.,* 2002). Soil organic carbon increase rapidly at the same rate as the solubility, decomposition and accessibility of organic matter increase. Carbon input into the soil decrease as plant health is adversely affected by poor soil physical and chemical conditions (Wong *et al.*, 2006). In salt-affected soils, increases in salt and sodium result in a decrease in soil carbon (Westerman *et al.*, 1974). The sparse vegetation cover of the selected sites suggest that plant health was adversely affected by the accumulation of salt and sodium and could possibly be attributed to the low organic carbon content of the soils.

5.1.5 Available Nitrogen

Availability of soil nitrogen is directly related to soil organic matter content and the extent of mineralization. Generally, salt-affected soils with sparse vegetation cover have low organic matter contents (Van Cleve *et al.*, 1996). The presence of accumulated salts and sodium affected plant health and possibly contributed to the low nitrogen levels of these soils.

5.1.6 Available Potassium

The availability of potassium in soils is associated not mainly with organic matter presence but may also be attributed to low soil pH (Kosmas *et al.*, 2000). The low pH of these soils could possibly account for the high levels of available K in these soils.

5.1.7 Available Phosphorus.

The low organic matter content together with the acidic nature of the soils, may explain the low available P levels in some of the profiles (Allotey *et al.*, 2008). Soils with high organic matter content cause reduced levels of phosphorus fixation. Therefore, the exceptional increments in P observed may be attributed to high organic matter content and proabable high adsorption of P to the soil colloids (Withers and Bailey, 2003).

5.1.8 Exchangeable cations

In all the salt-affected soils, decreasing trend in exchangeable cations with increasing depth was observed. Low pH in these soils could also be attributed to the low levels of calcium within the profile. The high exchangeable Na^+ content suggests that more salt was received by the soils due their proximity to the adjoining small lagoons. The surface horizon of these soils accumulated salt by capillary action, from the salty groundwater of nearby lagoons and wind deposits from the sea (Allotey *et al.*, 2008).

5.1.9 Exchangeable acidity

The values of exchangeable basic cations observed in these soils were higher than the values of exchangeable acidity. This is a probable indication that the soils are affected with salt. In a study by Nye *et al.,* (1961), if the cation exchange site is occupied by more than 60% of aluminium, aluminium toxicity in soils will result. Aluminium toxicity however, could not occur in these soils. The low pH observed could possibly be attributed to the presence of pyrite and low levels of exchangeable Ca^{2+} not Al^{3+}.

5.1.9.1 Effective Cation Exchange Capacity (ECEC)

Cation exchange capacity contribute to soil productivity. Soils with high CEC values are considered fertile except for saline soils. The cation exchange capacity of soils generally, ranged from a minimum of 2.0 $cmol_c$/kg in sandy soils to a maximum of 60 $cmol_c$/kg in clayey soils. At the lowest pH values of 3.71 and 3.93, ECEC values recorded were 18.82 $cmol_c$/kg and 38.29 $cmol_c$/kg respectively. This trend however, is inconsistent with the report that CEC increases with increasing pH.

5.1.9.2 Percent cation saturation

The ideal percent saturation range for soils are 60 - 80, 10 - 25 and 3 - 5 for calcium, magnesium and potassium, respectively (Bear and Toth, 1948). With the exception of magnesium and potassium, percent Ca^{2+} saturation was below the critical value. Higher concentration of exchangeable magnesium (Mg^{2+}) than exchangeable calcium (Ca^{2+}) may have contributed to soil structural aggregate instability because magnesium with a higher hydrated ionic radius than calcium, binds less effectively with soil colloids thus increasing electronegativity on the soil colloid and may contribute to repulsion of soil colloids. According to literature high rate of magnesium on soil exchange sites can lead to reduced water infiltration and potential soil erosion (Dontsova and Norton, 2002). This analogy is further supported by previous studies, which showed that magnesium ion could deteriorate soil structure when its concentration is higher than exchangeable calcium, when Ca: Mg ratio is 2:1 or 1:1. Also adsorbed magnesium adversely affect infiltration in montmorillonitic calcareous and non- calcareous soils. High exchangeable magnesium could as well be associated with adverse soil conditions of low conductivity and surface crusting exhibited in sodic soils (Yuan *et al*., 2007; Keren, 1996). However, the flocculation effect of magnesium out-ways its dispersion effect compared to sodium. Higher soil dispersion and poor drainage in this soils could possibly be attributed to high concentration of exchangeable sodium.

5.1.9.3 Percentage base saturation

Base saturation of 50 to 80 % is an indication of neutrality to alkalinity. However, with poor internal drainage (Appendix 3a, b, c and d) and leaching constraint of high neutral soluble salt of sulphate and chloride, the soils were extremely acid instead of being neutral or alkaline.

5.2 Soil characteristics for the pot experiment

The ESP values within the productive soil layer (0 to 30cm), were above 15 for soils taken from, Anyako, Anyenui, and Atiehife. EC was more than 4 dS/m, for all the soils. Salt-affected soils are rated according to the levels of their electrical conductivity and exchangeable sodium percentage as shown in Appendix 1 and 2. The results obtained suggest that Anyako, Ayenui and Atiehife soils were saline-sodic, based on salt-affected soil rating on electrical conductivity (EC) and exchangeable sodium percentage (ESP).

5.3 Chemical characteristics of the soil after harvest.

5.3.1 Soil pH

Gypsum application to soil causes an increase in salt concentration (Wong *et al*., 2009; Zia *et al*., 2006) and contribute further to increase in soil pH. Addition of gypsum was observed to be effective in increasing the soil pH, but it decreased gradually as the concentration of excess sodium decreased (Abrol *et al*., 1988). The mean of soil pH in the control pots also decreased at the end of the experiment. The observed trend could be attributed to the swelling and dispersive nature of the soil colloid, as water was continuously added. This affected drainage and possibly enhanced anaerobic condition, which caused an increase in CO_2 partial pressure within the root zone as a result of root and microbial respiration (Ponnamperuma, 1967, 1972, 1984; Robbins, 1985). The reduction in pH at higher level of gypsum application, could probably be attributed to the efficiency of Ca^{2+} to displace Na^+ and further leached out of the soil. This efficiency caused a reduction in the activity of exchangeable Na^+ to facilitate the hydrolysis of the clay colloids to form hydroxide, as reported by Ahmad *et al*., (2006). Reduction in soil pH is partly attributed to the reclamation of salt- affected soils (USDA, 1954). Atiehife soil recorded the highest reduction in the level of soil pH and the highest level of salt reclamation as compared to Anyako soil.

5.3.2 Soil Salinity (EC)

Soil electrical conductivity indicates the concentration of soluble salt in soil solution. Soil salinity (EC) produces osmotic effect and often causes physiological drought if it exceeds the critical limit for the crop (Grattan and Grieve, 1999). Regular removal of soluble salt from the pots through leaching contributed to the significant reduction in soil salinity in the pots treated with gypsum compared to the control. This may be attributed to the possible improvement in porosity and hydraulic conductivity and possible indication of soil reclamation. The observed trend is consistent with the report by (Chawla and Abrol, 1982).

5.3.3 Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is often used to assess the potential of excess exchangeable Na^+ to cause soil structure deterioration (Fatemeh *et al.,* 2013). The soil reclamation process became evident as SAR decreased to permissible limits (SAR< 13) in most of the treatments (Zaka et al., 2005); Richards, 1954). The reduction in SAR was essentially due to the displacement of excess exchangeable Na^+ from the soil colloidal complex and leached out of the soil in percolating water. This result is confirmed by (Hussain *et al.,* 2001; Clark *et al.,* 2007). The decline in SAR may be attributed to the gradual decline in the concentration of Ca^{2+}: Na^+ ratio within the soil solution as the efficiency of Na^+ displacement increased. The efficiency in the reduction of soil SAR was significantly higher in the application of gypsum at 13.49 g/pot compared to the other levels of gypsum application Ghafoor, (1984). This observation was probably due to the increase in the concentration of Ca^{2+} in the soil solution which enhanced the displacement process of adsorbed Na^+ as well as magnesium supported by subsequent leaching. The concentration of Ca^{2+} that remained in the soil solution after the displacement of Na^+ also decreased. This could be possible because Ca^{2+} moved to replace the displaced Na^+ at the exchange site causing a depletion of the amendment in the soil solution with time. This observation is consistent with (Suarez, 2001) who observed that the concentration of electrolyte in percolating water reduced significantly after the gypsum applied is completely dissolved. However, the observed decrease in SAR in the control treatment may as well be attributed to the disruption in the equilibrium position between monovalent and divalent cations at the colloidal exchange site and those in soil solution as water was continuously added to the soil such that movement of divalent cations to the exchange sites was favoured at the expense of the monovalent cations in the reclamation process (Reeve and Bower, 1960)

SECTION II

5.4 Rice growth parametres

5.4.1 The number of rice leaves, tillers and plant height

Excessive salt levels in the control treatment may have reduced the efficieny of nutrient uptake by the rice plant. Plant height, number of leaves and tillers decreased with salinity levels (Abdallah *et al.,* 2001). Growth of rice, was assessed partly, based on plant height and the number of leaves and tillers. The pattern of growth with respect to the number of tillers was similar to that of the number of leaves. Similar result was confirmed by LingHe *et al.,* (2000), who stated that the number of tillers per plant, decreased with increase in salinity level in rice and showed that the performance genotype for tiller production significantly varied under salinity stress.

The average height of the rice plant at the end of the first week was affected by the different levels of gypsum applied. The improvement in the height of NERICA L19 rice was related to the greater reclamation efficiency with respect to the soil chemical properties leading to the reduction in osmotic potential (Weon Yong *et al.,* 2003; Shannon *et al.,* 1994). The height of the rice plants were fairly the same at the end of week one. Slight increase in height was observed with increase in the level of treatments over the period.

Increase in the growth parameters (plant height, number of leaves and number of tillers) may be attributed to the reclamative effect of gypsum in reducing SAR, EC as well as improving the nutritional imbalance of the soils. A safe limit of salinity (ECe < $3dSm^{-1}$) was observed in all the treatments. According to Mahmood *et al.,* (2009), nutrient supplementation in the form of calcium (Ca) and sulphur (S) through the use of gypsum, contribute significantly to crop growth improvement. However, the antagonistic absorption of Na^+ at the expense of K^+ adversely affected the growth pattern of rice mostly in the control treatment (3.38, and 6.73 g/pot). Improvement in the soil properties obviously accounted for the increase in total plant biomass weight of harvested crop.

5.5 Tissue composition of NERICA L 19 rice

Reclamation of salt-affected soil, with gypsum, improved the availability of soil nutrient, conserved soil nitrogen and decreased sodium toxicity in the plant tissue. Tissue analysis of NERICA L19 rice, showed that gypsum application increased the concentration of calcium, phosphorus and potassium but decreased the concentration of sodium. The utilization of nitrogen however, was improved. According to (Grieve and Maas, 1988) interactions to suppress growth usually occur between calcium and sodium at high level of sodicity. However, the concentration of calcium in NERICA L19 rice tissue increased with increase in the level of gypsum applied compared to the control. This could possibly be attributed to the reduction in sodicity.

The concentration of magnesium in the leaf tissue increased with an increase in the rate of gypsum applied. This could be attributed to the increased displacement of magnesium into solution by calcium, making magnesium easily available for absorption by the plant.

The amount of sodium (Na) in rice tissue decreased with increase in the rate of gypsum applied to the soil. Meanwhile, due to the continuous leaching of soluble salts, the concentration of displaced Na^+ in the soil solution decreased as the rate of applied gypsum increased. This indication is however, consistent with the findings of (Suarez and Grieve, 1988) that as the concentration of Na^+ in soil solution increases the selectivity of sodium will increase at the expense of potassium.

The level of potassium availability in salt-affected soils is generally low. However, potasium uptake in the rice plant was influenced by the concentration of calcium in soil solution, by a selective mechanism of K transport relative to sodium. The observed trend is in agreement with the findings of Kinraide, (1998) who noted that calcium (Ca) improves K: Na selectivity in cell membrane, leading to less Na uptake and high K content in plant tissue. The marginal increase in K uptake could probably be attributed to the high electrolyte concentration Ca: Na ratio.

According to Fenn *et al.*, (1995), application of gypsum to soil provides a major source of calcium (Ca^{2+}) to influence the absorption of NH_4^+. This mechanism improves tillering, efficient use of nitrogen and enhances photosynthesis. The observed trend in nitrogen levels could possibly be attributed to the efficient use of nitrogen by the growing plant due to the improvement in soil properties.

Phosphorus availability in soil is influenced by the level of soil pH, organic matter and organic acid produced. According to Brauer *et al.*, (2005) an insoluble Ca-phosphate complex is formed when Ca^{2+} supplied from gypsum reacts with soluble P. However, the solubility of the Ca-phosphate complex formed gradually increases as the soil pH decreases with increase in organic acid produced. In this study total P accumulated in the rice leaf tissue increased as the rate of gypsum application increased from control to the addition of gypsum at 13.49 g. This margin of increase may be attributed to the increase in the solubility of Ca-phosphate complex formed, as the soil pH decreased with a corresponding decrease in the concentration and activity of sodium to facilitate the hydrolysis of the clay colloids (Ahmad et al., 2006)

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The morphorlogical description and classification of the three salt affected soils showed that, the soils were mainly clayey within the top soil with a high presence of pyrite, rusty root channels and yellowish brown mottles. Two of the soils Anyako and Anyenui were classified as Oyebi and the other Atiehife, was classified as Ada series respectively.

The application of gypsum to the soils, improved their chemical properties. Gypsum facilitated the leaching of Na^+ and salts and caused a significant reduction in soil salinity, sodicity and soil pH with a signicant increase in rice growth. Results obtained at end of the experiment indicate that EC and SAR of the soil in gypsum treated pots remained significantly lower than those in the non-gypsum treated pots. The improvement in soil properties in gypsum treated pots reflected positively in the number of leaves and tillers, plant height, biomass weight and ultimately rice growth.

Gypsum application at 13.49 g/pot significantly increased the growth of rice compared to the addition of gypsum at 3.38, 6.73 and 10.09 g/pot. Chemical analysis of the rice plant tissue showed that gypsum application increased the concentration of, potassium, calcium and magnesium and also improved the efficient use of nitrogen. The concentration of sodium however, decreased. High absorption of nitrogen by growing plant was observed when gypsum at 13.49 g/pot was applied. The pattern of growth and nutrient uptake was partly attributed to soil reclamation. Atiehife soil responded better to the reclamation process than the remaining soils with high growth performance. The pattern of growth and reclamation was in the order; Atiehife > Anyenui > Anyako.

6.2 Recomendation

Though, this research gave meaningful results considering the application of gypsum as an amendment, the use of small pots affected growth. This was possible because, displaced sodium (Na^+) did not accumulate beyond the root zone and probably caused nutritional imbalances. In order to strengthen furture research on salt-affected soils, the following recommendations have been outlined.

1. The use of larger pots involving soil reclamation in a controlled environment must be ensured to facilitate leaching of soluble salt. However, under field condition further test on NERICA L19 rice must be conducted to enable formulation of realistic recommendations for the local rice farmers.
2. The application of gypsum at the rate of 5.19 g/kg of soil showed improved performance in growth in the green house in respect of Atiehife, Anyenui, and Anyako soils. Further investigation is necessary to determine the optimum rates of gypsum application that will give optimum yield of NERICA L19 rice in the field.

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APPENDICES

APPENDIX 1: U. S. Salinity Laboratory Staff (1954) soil rating based on electrical conductivity and exchangeable sodium percentage (ESP)

EC and ESP range	Rating
EC < 4.0 and ESP < 15	Non-saline
EC > 4.0 and ESP < 15	Saline
EC < 4.0 and ESP > 15	Sodic

APPENDIX 2: Soil salinity rating based on electrical conductivity: FAO Soil Bulletin 39 (1988).

Soil salinity class	EC (dS/m)
Non saline	0–2
Slightly saline	2–4
Moderately saline	4–8
Strongly saline	8–16
Very strongly saline	>16

APPENDIX 3: Description of Selected Soils Used For the Experiment

Anyako
Soil Name: Oyebi series
Location: Anyako
Coordinates: lat. 06^0 00’09.5’’ long. 00^0 54’31.3’’
Parent Material: Alluvial
Rock outcrops: Nil
Natural vegetation: Coastal savanna and thicket
Land use: Not use and manage
Drainage: poorly drained
Moisture conditions: Moist
Depth of Groundwater: 130cm
Evidence of erosion: Slight sheet
Physiographic position: lower slope of the plain
Slope: 1 - 2%
Date of Description and sampling: 29th November, 2013

APPENDIX 3b

Anyenui
Soil Name: Oyebi series
Location: Anyenui
Coordinates: lat. 05^0 47’38.1’’ long. 00^0 43’30.0’’
Parent Material: Alluvial
Rock outcrops: Nil
Natural vegetation: Coastal savanna and Mangrove
Land use: Not use and manage
Drainage: poorly drained
Moisture conditions: Moist
Depth of Groundwater: 50cm
Evidence of erosion: Slight sheet
Physiographic position: upper slope of the plain
Slope: 1%
Date of Description and sampling: 29th November, 2013

APPENDIX 3c

Atiehife

Soil Name: Ada series
Location: Atiehife
Coordinates: lat. 00^0 53’00.2’’ long. 05^0 47’46.5’’
Parent Material: Alluvial
Rock outcrops: Nil
Natural vegetation: Coastal savanna, thicket and Mangrove
Land use: Not use and manage
Drainage: poorly drained
Moisture conditions: Moist
Depth of Groundwater: 100cm
Evidence of erosion: Slight sheet
Physiographic position: upper slope of the plain
Slope: 1%
Date of Description and sampling: 29th November, 2013

APPENDIX 3d

Agortoe

Soil Profile Description Status: Routine profile description
Atmospheric climate and weather condition: Sunny/ clear
Soil Temperature Regime: Isohypethermic
Soil Name: Ada series
Location: Agotoe
Coordinates: lat. 00^0 45’21.0’’ long. 05^0 51’39.2’’
Parent Material: Alluvial
Rock outcrops: Nil
Natural vegetation: Coastal savanna and thicket
Land use: Not use and manage
Drainage: poorly drained
Moisture conditions: Moist
Depth to Groundwater: 90cm
Evidence of erosion: Slight sheet
Physiographic position: higher part of the plain
Slope: 0.5%
Date of Description and sampling: 30th November, 2013

APPENDIX 4: Statistical Analyses

Chemical composition of the soils

Variate: Calcium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	1299.216	324.804	161.05	<.001
SOIL	2	10141.128	5070.564	2514.22	<.001
GYPSUM.SOIL	8	122.646	15.331	7.60	<.001
Residual	45	90.754	2.017		
Total	59	11653.744			

Variate: Magnesium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	1272.311	318.078	225.47	<.001
SOIL	2	2815.564	1407.782	997.92	<.001
GYPSUM.SOIL	8	91.280	11.410	8.09	<.001
Residual	45	63.482	1.411		
Total	59	4242.637			

Variate: Sodium (Na)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	41099.816	10274.954	1215.85	<.001
SOIL	2	738.677	369.339	43.70	<.001
GYPSUM.SOIL	8	2817.477	352.185	41.67	<.001
Residual	45	380.289	8.451		
Total	59	45036.259			

Variate: Potasium (K)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	84.0205	21.0051	190.90	<.001
SOIL	2	54.9818	27.4909	249.84	<.001
GYPSUM.SOIL	8	10.7291	1.3411	12.19	<.001
Residual	45	4.9515	0.1100		
Total	59	154.6829			

Variate: pH_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	17.132733	4.283183	648.69	<.001
SOIL	2	4.005703	2.002852	303.33	<.001
GYPSUM.SOIL	8	3.042097	0.380262	57.59	<.001
Residual	45	0.297125	0.006603		
Total	59	24.477658			

Variate: EC dS m

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	26.6243067	6.6560767	37914.36	<.001
SOIL	2	20.4560833	10.2280417	58261.00	<.001
GYPSUM.SOIL	8	2.8478833	0.3559854	2027.77	<.001
Residual	45	0.0079000	0.0001756		
Total	59	49.9361733			

Variate: SAR_mmol/cL

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	1368.9389	342.2347	1648.02	<.001
SOIL	2	142.2941	71.1470	342.61	<.001
GYPSUM.SOIL	8	89.7686	11.2211	54.03	<.001
Residual	45	9.3449	0.2077		
Total	59	1610.3465			

Rice growth parameters

Variate: NL

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	6505.975	1626.494	169.67	<.001
SOIL	2	1891.600	945.800	98.66	<.001
Week	3	33286.933	11095.644	1157.47	<.001
GYPSUM.SOIL	8	183.525	22.941	2.39	0.018
GYPSUM.Week	12	2201.025	183.419	19.13	<.001
SOIL.Week	6	1032.367	172.061	17.95	<.001
GYPSUM.SOIL.Week	24	134.675	5.611	0.59	0.939
Residual	180	1725.500	9.586		
Total	239	46961.600			

Variate: NT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	1179.767	294.942	234.91	<.001
SOIL	2	61.358	30.679	24.43	<.001
Week	3	3888.950	1296.317	1032.46	<.001
GYPSUM.SOIL	8	6.308	0.789	0.63	0.754
GYPSUM.Week	12	345.467	28.789	22.93	<.001
SOIL.Week	6	34.975	5.829	4.64	<.001
GYPSUM.SOIL.Week	24	6.358	0.265	0.21	1.000
Residual	180	226.000	1.256		
Total	239		5749.183		

Variate: PH_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	3978.10	994.53	78.21	<.001
SOIL	2	2293.46	1146.73	90.18	<.001
Week	3	15985.72	5328.57	419.06	<.001
GYPSUM.SOIL	8	183.17	22.90	1.80	0.080
GYPSUM.Week	12	849.12	70.76	5.56	<.001
SOIL.Week	6	272.44	45.41	3.57	0.002
GYPSUM.SOIL.Week	24	176.55	7.36	0.58	0.943
Residual	180	2288.80	12.72		
Total	239	26027.36			

Variate: FSW g/Kg soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	314.804	78.701	66.80	<.001
SOIL	2	31.260	15.630	13.27	<.001
GYPSUM.SOIL	8	0.828	0.104	0.09	0.999
Residual	45	53.020	1.178		
Total	59	399.912			

Variate: FRW g/Kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	627.948	156.987	48.08	<.001
SOIL	2	207.361	103.680	31.75	<.001
GYPSUM.SOIL	8	23.371	2.921	0.89	0.529
Residual	45	146.944	3.265		
Total	59	1005.623			

Variate: DSW g/Kg soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	301.274	75.319	74.37	<.001
SOIL	2	24.727	12.363	12.21	<.001
GYPSUM.SOIL	8	1.035	0.129	0.13	0.998
Residual	45	45.573	1.013		
Total	59	372.609			

Variate: DRW g/Kg soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	503.089	125.772	38.80	<.001
SOIL	2	158.302	79.151	24.42	<.001
GYPSUM.SOIL	8	27.774	3.472	1.07	0.400
Residual	45	145.877	3.242		
Total	59	835.041			

Variate: FSW + FRW g/Kg soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	1831.114	457.779	72.68	<.001
SOIL	2	393.380	196.690	31.23	<.001
GYPSUM.SOIL	8	30.946	3.868	0.61	0.761
Residual	45	283.444	6.299		
Total	59	2538.884			

Variate: DSW_DRW g/Kg soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	1581.136	395.284	65.31	<.001
SOIL	2	305.260	152.630	25.22	<.001
GYPSUM.SOIL	8	33.557	4.195	0.69	0.696
Residual	45	272.356	6.052		
Total	59	2192.309			

Tissue composition of Nerrica L19 rice

Variate: Ca mg/Kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	23164333.	5791083.	42.08	<.001
SOIL	2	15866333.	7933167.	57.65	<.001
GYPSUM.SOIL	8	16018667.	2002333.	14.55	<.001
Residual	45	6192500.	137611.		
Total	59	61241833.			

Variate: Mg mg/Kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	3464333.	866083.	4.11	0.006
SOIL	2	4774333.	2387167.	11.33	<.001
GYPSUM.SOIL	8	1960667.	245083.	1.16	0.342
Residual	45	9482500.	210722.		
Total	59	19681833.			

Variate: N_mg_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	127834250.	31958562.	110.49	<.001
SOIL	3	51678500.	17226167.	59.55	<.001
GYPSUM.SOIL	12	38767750.	3230646.	11.17	<.001
Residual	60	17355000.	289250.		
Total	79		235635500.		

Variate: K mg/Kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	1.27912	0.31978	16.14	<.001
SOIL	2	2.00133	1.00067	50.49	<.001
GYPSUM.SOIL	8	0.03048	0.00381	0.19	0.991
Residual	45	0.89180	0.01982		
Total	59	4.20273			

Variate: Na mg/Kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	9230667.	2307667.	21.11	<.001
SOIL	2	1612333.	806167.	7.37	0.002
GYPSUM.SOIL	8	564333.	70542.	0.65	0.736
Residual	45	4920000.	109333.		
Total	59	16327333.			

Variate: P mg/Kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GYPSUM	4	0.088127	0.022032	8.41	<.001
SOIL	2	0.050970	0.025485	9.73	<.001
GYPSUM.SOIL	8	0.024213	0.003027	1.16	0.346
Residual	45	0.117850	0.002619		
Total	59	0.281160			

ABBREVIATIONS

1. Available K ……………………………………Available potassium
2. Bray P……………….………………………..Available phosphorus
3. CEC…………………..………………………Cation exchange capacity
4. ECE……………………………………………...Effective cation exchange capacity
5. EC………………………………………………..Electrical conductivity
6. EDTA……………………………….……….Ethylenediaminetetraacetic acid
7. ESP……………………………………….……Exchangeable sodium percentage
8. EXCH.…………………………………………Exchangeable
9. ORG.C…………………………………………Organic carbon
10. ORG. M………………………………………...Organic matter
11. SAR ……………………………..……….…….Sodium adsorption ratio
12. WRB……………………………………………World reference base
13. CO_3^{2-}……………………………………………Carbonate
14. SO_4^{2-}…………………………………………….Sulphate
15. Cl^-……………………………………………..Chloride