Kwame Nkrumah University of Science and Technology

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IRRIGATION OF GROUNDNUT WITH WATER OF DIFFERENT SALINITY LEVELS AND THEIR EFFECT ON SOIL HYDRO-PHYSICAL PROPERTIES AND CROP PERFORMANCE

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MASTER OF SCIENCE

By

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ABSTRACT

This study was carried out to evaluate the different levels of salinity on some physical, hydrologic and chemical properties of soil in a greenhouse study. Groundnut was used as a test crop. Different levels of salinity on growth parameters and yield performance of groundnut were also investigated. The study was carried out at Soil Research Institute of the Council for Scientific and Industrial Research (CSIR), Ghana. The soil used was a chromic Lixisol from the Transitional Agro-ecological Zone of Ghana. Three levels of sodicity were used with zero salinity as the control. The experiment was a split plot design with Complete Block Design (CBD), with four replications. In this pot experiment, four seeds were sown per pot and later thinned to two. Saline treatments were imposed by irrigating each pot with water containing varying concentrations of sodium chloride. These concentrations corresponded with Electrical Conductivities (EC) of 2.0 dSm^{-1}, 4.0 dSm^{-1} and 6.0 dSm^{-1} respectively with 0.0 dSm^{-1} as the control.

The results indicated that salinity levels consistently increased the bulk density but decreased total porosity and air-filled porosity. Saliniity also consistently decreased soil infiltration rate. Sorptivity and apparent hydraulic conductivity also consistently decreased with increasing salinity levels. Salinity consistently decreased growth and significantly reduced the yield of groundnut. The residual moisture increased with increasing salinity levels indicating reduction in water uptake by the groundnut. Salinity also decreased the Evapotranspiration (ET) of groundnut. The residual nutrient contents of nitrogen, potassium and phosphorus increased as salinity levels increased indicating the reduced ability of groundnut to take up nutrients under high saline conditions.

Increasing concentration of sodium chloride concomitant increase in sodium concentration in groundnut leaves, which could be associated with nutrient imbalance effect caused by sodicity.

Salinity increased the bulk density while it decreased the porosity of soil. It also decreased water entry and movement in soil. Salinity had negative impact on growth and yield of groundnut.

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DEDICATION

This work is dedicated to Allah the Almighty, the One who was, who is and is to come, the author and source of all wisdom and knowledge, the architect of our survival, the giver of insight, and the father of all discoveries. Allah, my help in ages, past and hope for years to come.

And also, to my late parents for their love and support.

CERTIFICATION

The work in this thesis was conducted by the under signed candidate while enrolled in the Department of Crop and Soil Science at Kwame Nkrumah University of Science and

Technology, Kumasi-Ghana. No portion of this work has previously been submitted to another University for the award of a degree.

I certify that any help received in preparing this thesis and all sources used, have been acknowledged.

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Certified by Head of Department

Dr. J. V.K. Afun ……………………… Date……………….....

ACRONYMS

ANOVA	Analysis of Variance
AUD	Australian Dollar
BCM	Baylor College of Medicine

CEC	Cation Exchange Capacity
CSSRI	Central Soil Salinity Research Institute
dSm-1	DeciSiemens per litre
DW	Dry weight (mass)
ECdw	Electrical Conductivity of drainage water
ECEC	Effective Cation Exchange Capacity
ECiw	Electrical Conductivity of irrigation water
ECsw	Electrical Conductivity of soil water
ECth	Electrical Conductivity threshold
EDTA	Ethylene-DymineTetra-acetic Acid
EIA	Environmental Impact Assessment
ESF	Exchangeable Sodium Fraction
ESP	Exchangeable Sodium Percentage
ETc	Evapotranspiration concentration
FAO	Food and Agriculture Organization
FW	Fresh Weight (mass)
I.e.	That is to say
ICBA	Independent Community Bankers of America
ICID	International Commission on Irrigation and Drainage
ISTA	International Seed Testing Association
NSW	New South Wales
OC	Organic Carbon
OECD	Organization for Economic Co-operation and Development
OPfc	Osmotic Potential at Field Capacity
OPth	Osmotic Potential threshold
RSC	Residual Sodium Carbonate
RWC	Relative Water Content
SAR	Sodium Adsorption Ratio
SBI	Salt Balance Index
WRI	World Resource Institute

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Important of salinity in agricultural Production

Salinity of arable land is an increasing problem of many irrigated, arid and semi-arid areas of the world where rainfall is insufficient to leach salts from the root zone, and it is a significant factor in reducing crop productivity (Francois and Mass, 1994). This problem is not only reducing the agricultural productivity, but is also putting far reaching impacts on the livelihood strategies of small farmers (Tanwir *et al.*, 2003). Several major irrigation schemes throughout the world have suffered from the problems of salinity (Gupta and Abrol, 2000; Herczeg et al., 2001; Cai *et al.*, 2003; Sarraf, 2004). It is estimated that salinization of irrigated lands causes annual global income loss of about US$ 12 billion (Ghassemi *et al*., 1995), impacting aggregate national incomes in countries affected by degradation of salt-affected land and saline water resources. Generally, the worst salinity impacts occur where farming communities are relatively poor and face economic difficulties. In severe cases, salinization causes occupational or geographic shifting of the affected communities, with the male population seeking alternate off-farm income opportunities (Abdel-Dayem, 2005; Qadir *et al*., 2006). In terms of agricultural productivity, salinity can unfavourably affect plant growth, dry matter accumulation and yield (Sultana *et al*., 1999; Asch *et al*., 2000). The common cations associated with salinity are Na^+, Ca^{2+} and Mg^{2+}, while the common anions are

Cl^-, $SO4^{2-}$ and HCO_3. However the Na^+ and Cl^- are considered the most important, since Na^+ in particular causes deterioration of physical structure of the soil and both Na^+ and

Cl^- are toxic to plants (Dudley, 1994; Hasegawa *et al*., 2000).

Due to increase in population, there is competition for fresh water among municipal, industrial and agricultural sectors in several countries in the world. The consequence has been a decreased allocation of fresh water to agriculture (Tilman *et al*., 2002).

Due to scarcity of surface water resources, especially in arid and semi-arid region, for irrigation of agricultural lands, an intensive use of ground water with low quality has occurred, which has imposed a further increase in soil salinization (Poustini and Siosemardeh, 2004). It is estimated that up to 20 % of irrigated lands in the world is affected somehow by different levels of salinity and sodium content. In Iran for example,about 15% of lands, that is about 25 million ha, are suffering from this problem, including 0.32 million hectare of lands in Isfahan province (Feizi, 1993).

It is well known that dry mass of plants is reduced in proportion to the increase in salinity (Pardossi *et al*., 1999; Romero-Aranda *et al*., 2001). The reduction in growth of salinized plants may be related to salt-induced disturbance of the plant water balance, and in the extreme to a loss of leaf turgor which can reduce leaf expansion and therefore, photosynthetic leaf area (Erdei and Taleisnik, 1993; Huang and Redmann, 1995b). Other causes of growth reduction under salinity stress include ionic imbalances, change in nutrient and phytochromal status, physiological processes, biochemical reactions, or a combination of such factors (Volkmar *et al*., 1998 ,Hasegawa *et al*., 2000; Kashem *et al*., 2000a,b), accompanied by a reduction in photosynthesis (Sultana *et al*.,1999).

Salinity stress caused by sodium ion causes structural problems in soils created by physical processes such as slaking, swelling and dispersion of clay; as well as conditions that may cause surface crusting and hard setting (Shainberg and Letey, 1984; Sumner, 1993; Quirk, 2001). Such problems affect water and air movement, plantavailable water holding capacity, root penetration, runoff, and tillage and sowing operations. In addition, imbalances in plant-available nutrients in both saline and sodic soils affect plant growth (Naidu and Rengasamy, 1993; Qadir and Schubert, 2002).

As the agricultural use of salt-affected land and saline water resources plays a key role, their sustainable use for food and feed production will become a more serious issue (Suarez, 2001; Wichelns and Oster, 2006). In the future, sustainable agricultural systems using these resources should have good crop production with minimized adverse environmental and ecological impacts (Qadir and Oster, 2004). This will require a comprehensive approach to soil, water and crop management. Crop diversification and management are expected to play a key role.

Periodic collection of data and information on soil sodicity is a more meaningful measure of salt status and trend than traditional indirect methods. The Salt Balance Index (SBI) and Leaching Requirement (LR) estimated by indirect methods do not provide the absolute level of sodicity within the root zones of any crop of specific field within an irrigated target area. The trend of sodicity towards an increase or decrease should be known periodically. The effectiveness of irrigation and drainage design and of water table and sodicity control management can better be achieved by the periodic collection of information on soil sodicity level and distribution within the crop root zones is, regularly desired in the field rather than solely depending upon LR and SBI concepts.

1.2. Objectives

1.2.1 Main objective;

The main objective of this study was to investigate how induced sodicity can influence the growth and yield of groundnut and its effect on soil properties.

1.2.2 Specific objectives

The specific objectives of the study were:

(1) To assess the effect of salinity levels on some physical and chemical properties of soil;

(2) To calibrate sodium chloride concentration against electrical conductivity (EC);

(3) To investigate how salinity influences the hydrologic behaviour of soil;

(4) To explore the influence of salinity on growth and yield of groundnut;

(5) To investigate the influence of salinity on sodium concentration in groundnut leaves;

(6) To ascertain the cumulative impact of sodium chloride addition on the final EC of the soil.

Saline irrigation waters dominant in sodium salts limit the potential yield of groundnut directly by affecting physiological functions of plants or indirectly by degrading the soil environment.

1.2.3 Hypotheses;

- Irrigating with water of high sodium content creates saline conditions that affect both the physical and chemical properties of the soil.
- Saline soil influences the growth and yield of groundnuts.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Salinity and irrigation water quality

Saline soils are defined by Ponnamperuma (1984) as those that contain sufficient salt in the root zone to impair growth of plants. However, since salt injury depends on species, growth stage, environmental factors and nature of the salts, it is difficult to define saline soils precisely. The most widely accepted definition of a saline soil has been adopted from FAO (1997) as one that has an Electrical conductivity (EC) of the saturation extract of 4 dSm^{-1} or more, and soils with ECs exceeding 15 dSm^{-1} are considered strongly saline.

As competition for fresh water increases, water of better quality is used primarily for domestic purposes, whereas water of lower quality e.g. saline or polluted water often is used for irrigation (Khroda, 1996). One challenge for the future will be to maintain or even increase crop production with less water that may often be of poor quality, e.g. saline waters. Irrigation with saline waters is successfully practiced today in many countries such as Israel, Italy and the US (Rhoades *et al*., 1992). There seems to be a general lack of information on the prevalence and composition of saline aquifers in subSaharan Africa (Karlberg and de Vries, 2003). Nevertheless, some countries, such as South Africa, Botswana and Zimbabwe, have documented the presence of saline aquifers. Information on the extent to which saline water is being used for irrigation in sub-Saharan Africa is virtually lacking (Karlberg and de Vries, 2003).

The suitability of saline irrigation water must be evaluated on the basis of the specific conditions of use, including the crops grown, soil properties, irrigation management, cultural practices, and climatic factors. The ―ultimate‖ method for assessing the suitability of such waters for irrigation consists of:

1. Predicting the composition and matric potential of the soil water, both time and space resulting from irrigation and cropping;
2. Interpreting such information in terms of how soil conditions are affected and how any crop would respond to such conditions under any set of climatic variables (Rhoades, 1972).

Irrigation has the ability not only to increase the production per unit area of land but also to stabilize productions with minimum probability of crop failures. However, irrigation requires large water input, an essential commodity now in short supply but increase in demand. Conventional water supply of good quality water resource is increasingly becoming scarce, so saline groundwater, drainage water and wastewater sources are being used for irrigation. Shalhevel and Kamburov (1976) reported that waters with salinity as high as 6000 mg/l (0.6 %) have been used for irrigating salt tolerant crops. Mass (1990) reported successful irrigation of crops with salinity ranging from 1.3 to 9.4 dSm^{-1}. Rhoades (1992) emphasized the use of saline water and reuse of drainage water for crop production to meet food security demands. The poor quality saline and alkaline waters can be used for irrigation more effectively if tolerant crops as well as soil and water management practices are followed but there is little information about its social and economic consequences. Where the problem is acute, salinity will adversely affect agricultural production, soil fertility and environment (CSSRI 1995, 2000). It is imperative to develop appropriate approaches to study socio-economic aspects due to use of low quality irrigation waters and evolve economically viable techniques for the safe utilization of saline waters for irrigation to reduce economic losses for sustaining crop production in the saline environment. Two economic aspects are mainly involved: one relating to the reclamation of saline and sodic soils prior to cultivation by leaching or drainage and the other is to use saline water for irrigation directly.

2.2 Causes of Salinity

2.2.1 Primary causes

Most of the saline-sodic soils are developed due to natural geological, hydrological and pedological. Climatic factors and water management may accelerate salinization. In arid and semi-arid lands evapotranspiration plays an important role in the pedologenesis of saline and sodic soils. Wanjogu *et al*., 2001 reported that most of arid and semi-arid lands receive less than 500 mm of rainfall annually and this, coupled with an annual potential evapotranspiration of about 2000 mm leads to salinization.

2.2.2 Secondary Salinization

Secondary salinization affected soils are those that have been salinized by human caused factors, mainly as a consequence of improper methods of irrigation systems. Poor quality water is often used for irrigation, so that eventually salt builds up in the soil unless the management of the irrigation system is such that salts are leached from the profile. Ohara, (1997) has reported increasing salinity with increasing irrigation since 1950's.

Other human causes include deforestation, which is recognized as a major cause of salinization of most soils as a result of the effects of salt migration from both the upper and lower layers.

Overgrazing occurs mainly in arid and semi-arid regions, where the natural soil cover is poor and scarcely satisfies the fodder requirements of extensive animal husbandry. Because of overgrazing, the natural vegetation becomes sparse and progressive salinization develops, and sometimes the process ends up in desertification as the poor pasture diminishes, (Szabolcs, 1994).

2.3 The use of saline water for irrigation

The basic principle behind a sustainable agricultural system based on irrigation with saline waters is that the salt concentration in the soil has to be kept at relatively constant levels, below a threshold value specific for each crop species (Maas and Hoffman, 1977). To some extent this is a self-regulatory process by the plant (Shani and Dudley, 2001). When the soil salinity increases, the plant responds by decreasing water uptake. Thus more water is available for leaching of salts from the soil, thus reducing the salt content of the root zone. These feedback interactions by the plant and the soil salinity are further complicated by the processes of soil evaporation and drainage. Nevertheless, previous studies have shown that long-term sustainable agricultural system based on saline water irrigation can be established, provided appropriate management techniques are applied (Rhoades et al., 1992).

Karlberg and de Vries (2003) concluded that in areas where water causes limitations for irrigation, irrigation with saline water is a promising option provided the implementation is combined with appropriate management and training of the farmers. However, there is a need for further research to establish which management techniques are suitable and under what environmental conditions when saline water is combined with low-cost irrigation in sub-Saharan Africa.

Traditionally, four levels of saline irrigation water have been distinguished: low salinity defined by electrical conductivity of less than 0.25 mmhos/cm (0.25 dSm^{-1}); medium salinity (0.25 to 0.75 dSm^{-1}); high salinity (0.75 to 2.25 dSm^{-1}), and very high salinity with an electrical conductivity exceeding 2.25 dSm^{-1} (US Salinity Laboratory Staff, 1954). Later, it was realized that the reaction of crops to saline irrigation water was affected not only by the salinity level but also by soil characteristics, irrigation practices such as the type of system and timing and the amount of irrigation applications. Mass (1984) grouped the relative crop salinity tolerance rating in terms of soil salinity (EC) at which yield loss begins as given in Table 2.1

Table 2.1: Relative crop salinity tolerance rating Relative crop salinity tolerance Soil salinity (EC) at which yield loss begins dS/m^{-1}

Sensitive	>3
Moderately sensitive	1.3-3
Moderately tolerant	3-6
Tolerant	6-10
Unsuitable unless reduced yield is acceptable	>10

Source: Mass (1984)

2.4 Salinity problems and its effect on agricultural productivity

In general, three categories of salinity effects have been considered:

1) General growth suppression due to a low osmotic potential (Maas and Hoffman, 1977), especially during germination, emergence and early seedling growth (Mass *et al*., 1983; Aslam *et al*., 1988; Marschner, 1995)
2) Growth suppression caused by toxicity of specific ions (Maas, 1983; Yeo, 1993)
3) Growth suppression due to nutritional imbalance of essential ions (Munns and Termaat, 1986). Often, these different effects are indistinguishable and, in fact, the primary cause of salinity damage is not known. The effects of salinity/sodicity on plants are thus quite complicated and inseparable in some cases.

2.4.1 Effects of salinity on plants.

According to Dubey (1997) and Yeo (1998) salt causes both ionic and osmotic effects on plants and most of the known responses to salinity are linked to these effects. The general response of plants to salinity is reduction in growth (Romero-Aranda *et al*., 2001; Ghoulam *et al*., 2002). The initial and primary salinity, especially at low to moderate salt concentrations, is due to osmotic effects (Munns and Termaat, 1986; Jacoby, 1994). Osmotic effects of salts on plants are as a result of lowering water potential due to increased solute concentration in the root zone. Thus, in some species salt stress may resemble drought stress. However, at low or moderate salt concentration (high soil water potential), plants adjust osmotically and maintain a potential for the influx of water (Guerrier, 1996; Ghoulam *et al*., 2002). Plant growth may be moderated under such conditions, but in drought conditions, the plant must not be deficient in water (Shannon, 1984).

At high salinity, some specific symptoms of plant damage may be recognized, such as necrosis and leaf tip burn due to Na^+ or Cl^- ions. High ionic concentrations may disturb membrane integrity and function; interfere with internal solute balance and nutrient uptake, causing nutritional deficiency symptoms similar to those of drought (Grattan and Grieve, 1999).

The degree to which growth is reduced varies with species and to a lesser extent with varieties (Bolarin et al., 1991; Ghoulam *et al*., 2002). Salt accumulation in leaves causes‘ premature senescence, reducing the supply of assimilates to the growing regions and thus decreasing plant growth (Munns *et al*., 1995).

Romero-Aranda *et al*., 2001 suggested that induced water stress occurs as a result of salt accumulation at the soil/root interface. This accumulation results in a lower total water potential (Ψp), bringing about substantial difficulties in water uptake by plants. As the concentration of the external solution becomes hypertonic, the plasma membrane separates from the cell wall and shrinkage of the protoplast occurs. The space between the plasma membrane and the cell wall is filled with the extracellular solution. The outcome of this stress is a decrease in water content. There are many evidences which indicate that primary effects of salinity take place in roots and it is water deficit rather than specific ion toxicity (Munns and Termaat, 1986). Most of the rapid responses in leaf elongation rate to substrate salinity are attributable to changes in leaf water status

The quantity of ions delivered to the shoot per root mass and time, are a real measure of the plant‘s ability to adjust and in *Suaeda maritima*, the rate of Na^+ transport was much greater than in some non-halophytes even at moderately high external concentrations. The relationship of external water potential (Ψ) with the tugor pressure (P) and osmotic pressure (π) of plants (Dainty, 1979; Nobel, 1983; Tomos, 1988) is given by equation:

$$\Psi = P - \pi \qquad (1)$$

It is clear from the above equation that with decrease in Ψ of the medium, turgor maintenance will require an increase in π of the same magnitude. Turgor pressure affects growth as shown by equation (2) below (Lockhart, 1965).

$$r = \Phi\,(P - Y) \qquad (2)$$

where: r = rate of volumetric growth ($\mu m\ S^{-1}$)

Φ = cell wall extensibility (S^{-1} MPa^{-1})

P = turgor pressure (MPa)

Y = yield threshold

When plant is subjected to salinity, shoot injury occurs due to osmotic effect (Murty and Janardhan, 1971).

2.4.2 Effects of salinity on plant growth and yield.

Several investigators have reported plant growth reduction as a result of salinity stress, for example, in tomatoes (Romero- Aranda *et al*., 2001), cotton (Meloni *et al*., 2001) and sugar beet (Ghoulam *et al*., 2002). Tolerance to salinity differs among species as well as the growth parameters taken. For instance, Aziz and Khan (2001) found that the optimum growth for *Rhizophora mucronata* plants was obtained at 50 % seawater and declined with further increases in salinity while in *Alhagi pseudolhagi* (a leguminous plant), total plant mass increased at low salinity (50 mM NaCl) but decreased at high salinity (100 and 200 mM NaCl) (Kurban *et al*., 1999). In sugar beet leaf area, fresh and dry mass of roots were drastically reduced at 200 mM NaCl, but leaf number was less affected (Ghoulam *et al*., 2002). Fisarakis *et al*., (2001), were working with sultana vines reported large decrease in dry matter accumulation in shoots than in roots particularly at high NaCl concentration indicating partitioning photoassimilates in favor of roots. They proposed that the results may be due to a greater ability for osmotic adjustment under salt stress by the roots.

Crops vary not only in the rate at which they absorb a nutrient from a salt-affected soil, but also in the manner by which they distribute that element spatially within their bodies. Glycophytes have developed mechanisms for mineral nutrient absorption, transportation and utilization under non-saline and non-sodic conditions. Consequently, such nutrient-regulating mechanisms may not operate efficiently under saline and sodic conditions (Grattan and Grieve, 1999). Therefore, crop yield or plant biomass may be adversely affected by salinity- and sodicity-induced nutritional disorders.

2.4.3 Effect of salinity on plant water relations.

The main cause of reduction in plant growth may result from salinity effects on water status. According to Sohan *et al*., (1999) and Romero-Aranda *et al*., (2001) increase of salt in the root zone medium can lead to a decrease in leaf water potential and may affect many plant processes. At very low soil water potential, this condition can interfere with plant's ability to extract water from the soil and maintain turgor (Sohan *et al*., 1999).

Many authors reported that water and osmotic potential of plants became more negative with an increase in salinity, whereas, turgor pressure increased (Meloni *et al*., 2001; Romero-Aranda *et al*., 2001; Gulza *et al*., 2003). In the halophytes *Suaeda salsa*, Lu *et al*., (2002) found that leaf water potential and evaporation rate decreased slightly with increased salt concentration. Asraf (2001) reported similar decreases in leaf water potential with increasing salt concentration in all the six *Brassica* species studied.

Salt treatment caused a significant decrease in relative water content (RWC) in sugar beet varieties (Ghoulam *et al*., 2002). According to Katerji *et al*., (1997), a decrease in RWC indicates a loss of turgor that results in limited water availability for cell extension processes.

2.4.4 Effects of salinity on nutrient uptake.

High NaCl uptake competes with the uptake of other nutrient ions, such as K^+, Ca^{2+}, N, and P resulting in nutritional disorders and eventual reduction in yield and quality (Grattan and Grieve, 1999). Under salinity conditions, the uptake of N by plants is generally affected. A number of studies have shown that salinity can reduce N accumulation in plants (Feigin *et al*., 1991; Pardossi *et al*., 1999; Silveira *et al*., 2001). An increase in Cl^- uptake and accumulation has been observed to be accompanied by a decrease in shoot NO_3 concentration as in egg plants and sultana vines (Fisarakis *et al*., 2001).

In most cases, salinity decreased the concentration of P in plant tissues (Sonneveld and de Kreiji, 1999; Kaya *et al*., 2001), but in some studies, salinity either increased or had no effect on P uptake (Ansari, 1990). The reduction in P availability in saline soils was suggested by Sharpley *et al*., (1992) to be a result of ionic strength effects that reduced the activity of phosphates.

Salinity stress can cause an imbalance in the uptake of mineral nutrients and their accumulation within the plants (Grattan and Grieve 1992). Osmotic stress, ion imbalances, particularly with Ca^{2+} and K^+, and direct toxic effects of Na^+ and Cl^- ions on the metabolic processes are the most important and widely studied physiological impairments caused by salt stress (Munns 2002, Munns *et al*. 2006).

Research revealed that salinity inhibits the growth of plants by affecting both water absorption and biochemical processes such as N and CO_2 assimilation and protein biosynthesis (Cusido *et al*., 1987). Under saline conditions plants fail to maintain the required balance of organic and inorganic constituents leading to suppressed growth and yield (Gunes *et al*., 1996). Plant performance, usually expressed as a crop yield, plant biomass or crop quality (both of vegetative and reproductive organs), may be adversely affected by salinity induced nutritional disorders. These disorders may be as a result of the effect of salinity on nutrient availability, competitive uptake, transport or partitioning within the plant (Grattan & Grieve, 1999; Zhu, 2003; Ali *et al*., 2006a; Nasim *et al*., 2008).

Most studies indicated that salinity reduced Mn level in corn shoot tissue (Izzo *et al*., 1991; Rahman *et al*., 1993) and tomato (Alam *et al*., 1989). However, some studies exhibited that salinity either had no effect (Al-Harbi, 1995) or increased Mn (Niazi and Ahmed, 1984) in leaf or shoot tissue of tomato. Many studies have shown that salinity increased Zn concentration in shoot tissue such as in citrus (Ruiz *et al*., 1997), maize (Rahman *et al*., 1993) and tomato (Knight *et al*., 1992), but in other studies it was not affected (Izzo *et al*., 1991) or actually decreased Zn concentration as in case of cucumber leaves (Al- Harbi, 1995). Reports also stated that Fe, Mn, Cu and Zn concentrations were higher in roots compared with those in leaves and stem in salt applied samples of 12 soybean cultivars (Tunçturk *et al*., 2008).

2.4.5 Effects of salinity on agricultural productivity.

The effects of salinization on agricultural productivity can be severe. However, water logging and salt accumulations in agricultural land affect plant growth adversely and reduce crop production. In the advanced stages, plants can be killed and the land, rendered unusable. Salinization and sodication could limit the soil‘s productivity, leading to fertility reduction (Al- Zu‘bi, 2007) and if the level of Na+ in the soil is high, the colloidal fraction behavior will be affected. Salinization of agricultural land causes massive economic loss at the global level. Ghassemi *et al*., (1995) estimated the annual global income losses due to salinization of agricultural land at US$11.4 billion in irrigated land and US$1.2 billion in non-irrigated areas. Hayes (1997) estimated losses due to salinity in the Murray-Darling basin alone at US$ 91 million per annum and they have been predicted to reach US$ 350 million per annum by 2025 (NSW Legislative Assembly 2004). For the Colorado River Basin, estimates of damage due to salinity run into US$ 300 million per annum (Barnett 2005).

Salinity causes direct and indirect effects on the environment in general by inducing changes in vegetation cover and physical and chemical soil properties. It can cause loss of biodiversity, impacts on wildlife (Barnum 2005) and disruption of ecosystems leading to loss of ecosystem function (Barrett- Lennard et al. 2005) that affect local climate and water cycles. All these effects of salinity impact communities inside and outside irrigated areas and the social and economic costs have to be paid by society at large (Abdel-Dayem 2005).

Other negative impacts include soil erosion by surface runoff, deep percolation of excess irrigation water often causing water logging and groundwater degradation, and damage caused by inadequate disposal of saline drainage water.

2.5 Effects of salinity on soil chemical properties

The accumulation of salts in the root zone and the associated chemical processes is often referred to as salinization and this process ultimately causes sodication (soil degradation associated with the presence of sodium ions in the soil solution), but at different rates. The Soil Science Society of America (SSSA) (1997) defined salinization as soil containing sufficient soluble salts to adversely affect crop production and soil structure under most conditions of soil and plant type.

In Georgia, on relatively sandy soil with low organic matter content, Truman and Rouland (2005) found high erosion risk when a supplementary irrigation system was used. Natural water has different salt concentrations and qualities, and contains principally salts of high solubility like sodium, calcium, magnesium and potassium chlorides and sulfates.

When soil solution is more concentrated due to evaporation and plant water uptake, sodium becomes the predominant ion in the soil, through cation exchange, on the exchange complexes of the soil matrix. This is the process of sodication, which occurs rapidly. Once Na predominates on the exchange complex, the soil is sodic. This type of soil is unstable and becomes degraded: it loses its structure due to mechanical effects, such as the impact of rain drops and tillage, and the clay minerals disperse as a result of geo-chemical processes.

2.5 Effects of salinity on soil physical properties.

Soil water salinity can affect soil physical properties by causing fine particles to bind together into aggregates especially with calcium salts. This process is known as flocculation and is beneficial in terms of soil aeration, root penetration, and root growth. Although increasing soil solution salinity has a positive effect on soil aggregation and stabilization, at high levels salinity can have negative and potentially lethal effects on plants (Bauder and Brock, 1992).

The primary physical processes associated with high sodium concentrations are soil dispersion and clay platelet and aggregate swelling. The forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion.

Soil dispersion causes clay particles to plug soil pores, resulting in reduced soil permeability. When soil is repeatedly wetted and dried and clay dispersion occurs, it then reforms and solidifies into almost cement-like soil with little or no structure

(Mamedov *et al*., 2000).

Suarez *et al.* (2006) found that with high ESP and low electrolyte concentration, clay, as well as organic matter begins to swell and disperse, causing negative physical effects such as restricted aeration and permeability.

Thus, apart from swelling and dispersion of clay particles, slaking of soil aggregates is one of the main causes of soil degradation. Slaking is the disaggregation of soil particles into smaller units under the influence of mechanical forces, when the forces associated with osmotic swelling and air entrapment exceed the binding forces in the soil. Dispersion and slaking together lead to the formation of surface crusts and hard layers in the soil profile, which hamper infiltration and water movement through the soil profile. In sodic soils, it also narrows the range of water contents over which water is readily available (the non-limiting water range); (Jayewardene and Chan 1993). As soil clays are more readily dispersed under the influence of mechanical energy inputs (Sumner 1993), the infiltration rate (IR) is much more sensitive to increasing levels of Na than the hydraulic conductivity of the soil at greater depth.

2.5.1 Effects of salinity on soil hydraulic Conductivity

Soil dispersion not only reduces the amount of water entering the soil, but also affects hydraulic conductivity of soil. Hydraulic conductivity refers to the rate at which water flows through soil. For instance, soils with well-defined structure will contain a large number of macropores, cracks, and fissures which allow for relatively rapid flow of water through the soil. When sodium-induced soil dispersion causes loss of soil structure, the hydraulic conductivity is also reduced. If water cannot pass through the soil, then the upper layer can become swollen and waterlogged. This results in anaerobic soils which can reduce or prevent plant growth and decrease organic matter decomposition rates. The decrease in decomposition causes soils to become infertile, black alkali soils.

2.6 General responses of plants to salinity

Initially salt affected plants appear normal although they are stunted and may have dark green leaves which, in some cases, are thick and are more succulent. Species and varieties of various plants differ greatly in their response to salinity of root medium (Saqib *et al*., 2005; Ali *et al*., 2006b; Tahir *et al*., 2006; Nasim *et al*., 2008). Researchers also reported that response of a plant to salinity varies with its age thereby altering the degree of salt tolerance (Ashraf and O'Leary, 1994; Ashraf & Sharif, 1998; Ashraf & Harris, 2004; Qasim and Ashraf, 2006; Raza *et al*., 2006), although in some other studies the reverse was true since the salt tolerance in them was not age dependant (Ashraf & Fatima, 1994, and 1995; Ashraf *et al*., 1994; Ashraf and Tufail, 1995). However, of the various plant responses to salt stress, pattern of ion uptake is of prime importance since it determines the means whereby plants maintain water balance and avoid Na^+ and/or Cl^- toxicity under saline conditions (Munns *et al*., 2000).

In some plant species, for instance in euhalophytes, salinity sometimes affects growth positively, except for some C4 species like *Atriplex*, where Na^+ is needed as a micronutrient (Flowers and Lauchli, 1983).

2.7 Improving soil physical properties of salt affected soils

Crop diversification options under salt-affected environments not only provide economic or on-farm benefits to farming communities, but also help in environment conservation through improvements in physical properties of salt-affected soils and decreases in salinity and sodicity levels. Additional benefits include improvement in the availability status of nutrients and carbon storage in the post-plantation soil. Various field-scale evaluations reveal such benefits from crop-based management of saltaffected land and saline water resources (Qadir and Oster, 2004).

Ahmad et al. (1990) tested three plant species—Kallar grass, sesbania, and sorghumsudan grass hybrid _sordan'—for biomass production and amelioration of a calcareous, sandy clay loam, saline-sodic field (pH 8 to 2 to 8 to 6, EC 7 to 4 to 9 to 0 dSm^{-1}, SAR 55 to 6 to 73 to 0). The plant species were grown for two seasons (15 months). Their efficiency as indicated by a decrease in SAR in the upper 0 to 3m of soil was as follows: sesbania (30 to 1), Kallar grass (32 to5), sordan (40 to 0), control (57 to 2). Sesbania yielded the largest amount of seasonal forage, providing 40 to 8 t ha^{-1} of fresh biomass. Smaller amounts of forage were yielded by Kallar grass (29 to 3 t ha^{-1}) and sordan (24 to 7 t ha^{-1}), indicating a direct relationship between forage production and decreases in soil sodicity. The amelioration potential of sesbania was also equivalent to application of gypsum to the soil.

Planting salt-tolerant N_2-fixing trees has been a common approach to rehabilitate saltaffected degraded lands in many parts of the world (Oba *et al.*, 2001; Kaur *et al.*, 2002). Tree plantations and silvo-pastoral systems have been reported to ameliorate the conditions and fertility of sodic soils in India by improving soil's organic matter and availability of inorganic N (Kaur *et al*., 2002).

Mishra and Sharma (2003) found that growing mesquite and shisham on a sodic soil (pH 10, ESP 71) progressively improved the soil's chemical and physical properties. Nine years after planting, there was a significant decrease in exchangeable Na ion levels, i.e. 3 to 5-fold in the surface soil under mesquite plantation. The corresponding decrease for the 9-year-old shisham plantation was 2 to 7-fold. The rate of decrease in exchangeable Na ion levels was more pronounced in the initial 3 years. In addition to soil sodicity amelioration, there was a significant improvement in soil organic carbon, exchangeable Ca^{2+} ion and Mg^{2+} ion, total N, plant-available K and P, soil porosity, water-holding capacity and soil permeability.

Australian researchers (Marcar and Crawford, 1996; Marcar *et al*., 2003) have amelioration of saline soils along with other direct benefits (firewood and saleable products) as well as indirect gains (increased agricultural productivity, enhanced biodiversity and carbon sequestration. Among the species studied, A. stenophylla, Eucalyptus camaldulensis, E. occidentalis, and E spathulata performed best in terms of soil amelioration under conditions where the EC of the soil ranged from 4 to 13 dSm^{-1}.

2.7.1 Leaching requirement

The leaching requirement concept requires the application of additional water over the

Evapotranspiration (ET) demand for preventing the buildup of salts in the root zone. The actual fraction of applied water (irrigation and rainfall) that passes through the root zone and carries dissolved salts below the root zone is termed as leaching fraction.

According to Ragab (1998), the leaching requirement (LR) is usually calculated by the following equation.

$$LR = \frac{Dd}{Di} = \frac{Cd}{Ci} \qquad (3)$$

where, Dd is the depth of water passing below the root zone as drainage water

Di is the depth of applied irrigation plus rainfall water

Cd is the salt concentration of the drainage water above which yield reduction occurs

Ci is the salt concentration of irrigation water

The leaching fraction (LF) is determined by the following equation.

$$LF = \frac{\text{Water depth applied at surface}}{\text{Water depth leached below root zone}} \qquad (4)$$

A high leaching fraction (LF = 0.5) results in less salt accumulation than a lower leaching fraction (LF = 0.1). If the water salinity (ECiw) and the leaching fraction (LF) are known or can be estimated, both the salinity of the drainage water that percolates below the rooting depth and the average root zone salinity can be estimated. The salinity of the drainage water can be estimated by the following equation.

$Eciw$

$$Ecdw = \frac{}{LF} \quad (5)$$

ECdw is the salinity of the drainage water percolating below the root zone (equal to salinity of soil water, ECsw

ECiw is the salinity of applied irrigation water

LF is the leaching fraction

2.7.2 Nutrient management for saline soils

The fertility of salt affected soils is generally poor. Crops grown on these soils invariably suffer nutritional disorder, resulting in low yield. The removal of nutrients from plants is also a matter of serious concern. The ‗nutritional security' for the growing population in the world can be achieved only when the availability of sufficient nutrients to the plants is adequately assured. The plant nutrient losses due to erosion, runoff and leaching are of high order, and therefore, effective nutrient management programme is of vital importance for optimizing crop production on salty soils.

Nitrogen is one of the most important fertilizer nutrients required for crop production. Salt affected soils are low in organic matter and so more deficient in available nitrogen. The Volatilization loss of soil N is a major constraint to crop production, particularly rice grown on flooded soil under higher salinity and soil water content.

2.8 Carbon sequestration and energy capture

The need to develop clean, renewable energy sources to replace hydrocarbons is driving the exploration of many options, including biomass production. Because of the scale of likely future needs, however, biomass production for carbon sequestration and energy production is likely to be practical only if it can be carried out using resources that do not compete with food production and show net carbon sequestration (i.e. carbon sequestered in biomass minus that produced during the process of manufacturing the necessary equipment, decay of organic matter, fuel burned in the process and so on). The large unutilized desert areas of the world could fit that requirement, but of course lack water. The possibility of using seawater or other unutilized sources of saline or polluted water to irrigate desert areas for sustainable biomass production is therefore receiving serious consideration in many quarters (Ahmed and Abdullah 1979; Glenn *et. al*., 1996).

2.9 Socio-economic impacts of saline water use

The major purpose of irrigated agriculture is to increase agricultural production and consequently improve the economic and social status of the inhabitants. The environmental impact assessment (EIA) needs to concentrate on means in which positive impacts can be enhanced (FAO, 1997). The socio-economic factors include: population change, income and amenity, women‘s role, minority groups, and user involvement (participation). Generally, in the case of saline water irrigation, the economic aspects have three major parts: (i) relating to the reclamation of saline and sodic soils prior to cultivation; (ii) the continuous use of saline water for irrigation and; (iii) the drainage installations and reuse of drainage water for irrigation. Shalhevet and Kamburov (1976), a worldwide survey on irrigation and salinity reported that the farm income was reduced in the saline-affected Kerang region by 73 % as compared to nonsaline Shepparton region in Victoria, Australia. A leaching experiment in Iran

(Karkheh, Khusistan) demonstrated very substantial yield increase. In Republic of China, the net increase in productivity due to reclamation was equivalent to 2.5 to 3 tons/ha^{-1} of sugar. Waterlogging and salinity drastically reduced cotton yield. In the Euphrates River valley, salinity in its various degrees caused a 70000 ton/year loss in cotton yield, which, at 1970 prices, was equivalent to 17 million US dollar

Farmers have practiced agriculture with saline waters under various resources and institutional constraints. The resource constraints are mainly: insufficient and untimely availability of good quality waters; non availability to salt tolerant hybrid yield varieties of seeds, organic material and amendments; and high cost on energy and tube well installation. The institutional constraints are: small size holdings, fragmentation of holdings, and non-availability of credits (Abdel-Dayem 2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Background of the study area

This study was conducted in the laboratories and green house of Soil Research Institute, Kwadaso, Kumasi-Ghana. Kumasi lies approximately on latitude 6^{0} 41 N and longitude 1^{0} 38 W. Rainfall in Kumasi is bimodal with a mean annual total of about 1,302 mm.

The minor dry season occurs in August and the major dry season starts from midNovember and ends in February. The main wet season is from Match to July whilst the minor rainy season extends from September to November. Temperatures are uniformly high throughout the year. The lowest mean annual temperature of about 24.6 ^{0}C is usually recorded in August and the highest mean monthly temperature of about 28.8 occurs in February. Morning relative humidity is uniformly high throughout the year.

The mean monthly figures range between 84.4 and 95.6 % at 06.00 h and 39.6 and 75.1 % at 15.00 h. The annual evapo-transpiration in Kumasi is about 1234 mm with monthly values ranging from 107 to 144 mm in the major dry season and 71 to 118 mm in the rainy season (Mensah, *et al*., 2008). Local meteorological data (temperature and relative humidity) within the period of the experiment were gathered at the green house of the Soil Research Institute, Kwadaso using a hygrometer and temperature indicator (Appendix plate 1) and (Appendix 16).

3.2 Soil used for the experiment:

The soil used for the experiment is classified locally as Bidiesi series or Chromic Lixisol, by FAO UNESCO classification. The soil samples were collected near Mampong, Ashanti located in the Forest- Savanna Transitional agro-ecological zone of Ghana.

3.3 Soil sampling procedure

The following procedures were used for collecting the soil samples. The area to be sampled was cleared of any surface debris (e.g., twigs, rocks, litter). An area of approximately 10 cm in radius was created around the sampling location. Gradually, the auger was inserted into the soil by applying a downward force while rotating it. Once filled at the correct depth, the auger was removed and the top soil placed into a clean, dry container marked ―top soil‖. Augering was carefully done to prevent accidental brushing of loose material back down the borehole when removing the auger.

The immediate top layer of the soil was carefully removed with a spade and the debris discarded. The samples were collected from 0-15 cm depth, transferred into empty rice bags and fastened with a rope to avoid spilling.

3.4 Soil preparation and packaging in plastic containers (pots)

From the field, soils were emptied from the bags and spread to dry on flat polyethylene sheet for air for eight (8) days. After air drying, the soil samples were passed through a 2 mm (10 meshes) sieve (Plate 2) to give what is commonly referred to as 2 mm fine earth which is used for most analyses. After sieving, stones and pieces of plant materials were discarded. The soil samples were bulked together and packed into the various experimental pots of 20.3 cm height, 24.0 cm in diameter at the top and 10.5 cm at the bottom to a known bulk density of 1.3 g cm^{-3} so as to ensure equal amount of soil in each pot. The volume of the plastic pot was estimated by noting the volume of water required to fill the pot from a measuring cylinder.

Plate 1: Soil preparation and packaging into experimental pots

3.5 Calibration of the electrical conductivity (EC) against sodium chloride concentration:

To calibrate the EC, 2.54 g of NaCl were weighed and added to 1000 ml of distilled water to obtain 1000 ppm Na. The conductivity meter was then calibrated using 0.01 M KCl to get the normal mode. From the 1000 ppm NaCl solution, 15 ml were withdrawn and diluted to different concentrations. The electrodes were dipped into the different solutions respectively to give the different electrical conductivity (EC) levels. This solution was then used to check for the different salinity levels with the aid of an

Electrical Conductivity Meter (Hanna Instrumental Conductivity Meter model Hi 9032).

The results obtained were used to plot the graph with the aid of a computer using the Microsoft software as shown in Fig. 1 of the results.

3.6 Laboratory determination of soil properties

The pertinent properties were determined on composite soil samples before sowing using the standard procedures.

3.6.1 Particle size

The particle size distribution was determined by the Bouyoucos hydrometer method.

Fifty grams (50 g) of the soil sample were weighed into beakers into which 50 ml of Calgon composed of 80 g of sodium hexasulphate and 20 g sodium hydrogen carbonate were added and topped up with 200 ml of distilled water. The samples were then placed on an electric heater until they started to boil. The samples were then quickly transferred into a dispersion mechanical mixer until the soil aggregates were broken. (This usually took about 3-4 minutes for coarse-textured soils and 7-8 minutes for finetextured clay). The first hydrometer and temperature readings were taken at 40 seconds. After the first readings the suspension was allowed to stand for three hours and the second hydrometer and temperature readings taken. The first reading indicates the percentage of sand and the second reading percentage clay. The percentage of silt was determined by the difference.

Calculations:

$$\% \text{ Sand}=100-[H_1 + 0.2 (T_1 - 20) -2.0] \times 2 \quad (6)$$

$$\% \text{ Clay}= [H_2 + 0.2 (T_2 - 20) - 2.0] \times 2 \quad (7)$$

$$\% \text{ Silt}= 100-(\% \text{ sand} + \text{clay}) \quad (8)$$

where:

H_1 = Hydrometer reading at 40 seconds

T_1 = Temperature at 40 seconds

H_2 = Hydrometer reading at 3 hours

T_2 = Temperature at 3 hours

0.02 (T-20) = Temperature correction to be added to hydrometer reading –2.0

= Salt correction to be added to hydrometer reading

3.6.2 Organic carbon determination

Organic carbon was determined by the modified Walkley and Black wet oxidation method (Nelson and Summers, 1982) (Plate 3). Two grams (2 g) of the soil sample were weighed into a 500 ml Erlenmeyer flask and a blank sample was also included. Ten milliliters of 1.0 N Potassium Dichromate ($K_2Cr_20_7$) solution was added to the soil and the blank flask. To this, 20 ml of concentrated sulphuric acid was added and the mixture allowed to stand for 30 minutes on an asbestos sheet. Distilled water (200 ml) and 10 ml of concentrated Orthophosphoric acid (H_5PO_4) were added and allowed to cool. The excess dichromate ion ($Cr_20_7^{-2}$) in the mixture was back titrated with 1.0 M ferrous sulphate solution using diphenylamine as indicator.

The organic carbon (OC) was calculated by the formula:

% Organic C = (m.e. $K_2Cr_20_7$-m.e $FeS0_4$) x (1.32) x 0.003 x 100/wt. of soil (9)

where m.e.= normality of solution x ml of solution used,

0.003 = m.e. wt. of C in grams (12/4000),

1.32 = correction factor

Plate 2: Determination of organic carbon

3.6.3 Soil pH determination

Soil pH was determined by calibrating the pH reader (Hanna Instrumental pH Meter, model Hi 9032), using two buffer solutions, one buffer with neutral pH (7.0) and the other pH (4.0). The electrodes were then inserted into the beakers containing the two solutions alternatively, and the pH adjusted as required. Twenty-five (25) grams of the soil sample were weighed into a 100 ml beaker, and 25 ml of distilled water was added as a suspension medium. Samples were then stirred intermittently for 30 minutes using a glass rod. Using the calibrated pH meter, the pH readings were recorded.

3.6.4 Electrical conductivity (EC)

Electrical conductivity was determined by electrical conductivity meter (Hanna

Instrumental Conductivity Meter, model Hi 9032) in 1:2 soil water ratio (Jackson 1973). Forty (40) grams of the soil sample were weighed and placed into a 250 ml flask and 80ml of distilled water added. The conductivity electrodes were then washed with distilled water and rinsed with standard KCL solution. The conductivity meter was adjusted to read 1.412 mS/cm, corrected to 25 ^{0}C. The electrodes were then washed and dipped into the soil extract and the digital displays were recorded as the salt content in the extract, and an indication of salinity status of the soil sample.

3.6.5 Determination of calcium

For the determination of calcium, a 10 ml portion of the extract was transferred into an Erlenmeyer flask. To this, 10 ml of potassium hydroxide solution was added followed by 1 ml of triethanolamine. Few drops of potassium cyanide solution and few crystals of cal-red indicator were then added. The mixture was titrated with 0.02 N Ethylene diamine tetraacetic acid (EDTA) solutions from a red to a blue end point.

3.6.6 Determination of calcium and magnesium

Calcium and Magnesium were determined by Versanate Ethylene-DymineTetra-acetic Acid (EDTA) method. Five (5) grams of the air-dried soil were placed into a 150 ml flask and mixed with 25 ml of ammonium acetate solution. The mixture was shaken with a mechanical shaker for five minutes, and filtered through No.1 filter paper. An aliquot of 5ml was pipetted and 3-4 drops of EBT indicator were added. The solution was titrated with 0.01 N versanate for a colour change from blue to bright-blue or green.

A blank titration was also carried out without soil.

Calcium and Magnesium were calculated by the formula:

$$\text{Ca + Mg (or Ca) (cmol/kg soil)} = 0.02 \times V \times 1000/W \qquad (10)$$

where: W= weight in grams of soil extracted

V= ml of 0.02 N EDTA used in titration

0.02= concentration of EDTA used

3.6.7 Determination of available potassium

Potassium present in the soil was extracted with neutral ammonium acetate of 1 molarity. This is considered as plant-available K in the soil. It was estimated with the help of a flame photometer (Toth and Prince, 1949). A standard curve was prepared by atomizing the flame photometer to 0 and 20 µg K per ml solutions alternatively to readings of 0 and 100. These readings were then plotted against the K contents and the points connected with a straight line to obtain a standard curve. Then 5 g of the soil sample were mixed with 25 ml of the ammonium acetate extractant into a conical flask and shake for five minutes and filtered. The potash in the filtrate was determined with the flame photometer. The calculation is:

$$k\left(\frac{kg}{ha}\right) = \frac{A}{1000{,}000} \times \frac{25}{5} \times 2{,}000{,}000 \qquad (11)$$

where A = content of K (µg) in the sample, as read from the standard curve;

Volume of the extract = 25 ml;

Weight of the soil = 5 g;

Weight of 1 ha^{-1} to a plough depth of 22 cm is taken as 2 million kg

3.6.8. Determination of Phosphorus

Brays method No.1

A standard curve was prepared by dissolving 0.3 g of pure dry KH2PO4 in 1 litre of distilled water. Ten milliliters (10 ml) were taken from the solution and diluted to 0.5 millitres with distilled water. Then 0, 1,2,4,6 and 10 ml of these solutions were put separately into a 25 ml flask. Into each of these flasks, 5 ml of the extraction solution and 5 ml of the Molybdate agents were added and diluted with distilled water to about 20 ml. 1 ml of dilute $SnCl_2$ solution was added, shaken and diluted to 25 ml mark. After 10 minutes, the blue colour was read from the spectrophotometer at a wavelength of 660 nm. The absorbance readings were then plotted against ―µg P‖ and the points were connected.

After the preparation of the calibration curve, 5 g of the soil sample was weighed and 50 ml of Bray‘s extractant No.1 were added into a 100 ml conical flask. The sample was shaken for 5 minutes and filtered. From the filtrate, 5 ml were taken with a bulb pipette into a 100ml flash and 5ml of the Molybdate reagent were added with another 1 ml of $SnCl_2$. After 10 minutes, the blue colour was read from the spectrophotometer (Plate 4) at 660 nm after setting the instrument to zero with the blank prepared similarly but without the soil.

The calculation was done using the following equation:

$$P\left(\frac{kg}{ha}\right) = \frac{A}{1,000,000} \times \frac{50}{5} \times \frac{2000,000}{5} \qquad (12)$$

where: The mass of the soil taken = 5 g;

Volume of the extract = 50 ml:

Volume of extract taken for estimation = 5 ml;

Amount of P observed in the sample on the standard curve = A (µg):

Mass of 1 ha^{-1} of soil down to a depth of 22 cm is taken as 2 million kg.

Plate 3: Determination of available phosphorus using spectrophotometer

3.6.9 Total nitrogen determination

Total nitrogen was determined using the Kjeldah digestion method and distillation procedure as described by Bremner and Mulvaney (1982). A 10 gram of the soil sample was weighed into a Kjeldahl digestion flask and digested and 10 ml distilled water added to it. Concentrated sulphuric acid and selenium mixture (selenium 40 g and copper sulphate 20 g) were added and mixed carefully The samples were then digested on an

Kjeldahl apparatus for 3 hours until the solution was clear. The samples were then removed from the digester and allowed to cool after which the volume of the solution was made to 100 ml with distilled water. A 10 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of NaOH solution was added followed by distillation. The distillate was collected in boric acid and titrated with 0.1 N HCL solutions with bromocresol green as indicator. A blank was also run in a similar manner but without the soil sample.

Calculation was done using equation 13 below:

$$\%N = (A - B) \times 14N \times \frac{100}{1000 \times 1} \qquad (13)$$

where: N = concentration of HCL used in titration

A = ml HCl used in sample titration

B = ml HCl used in blank titration

14 = atomic mass of nitrogen

1 = mass of soil sample in grams

3.6.10 Determination of exchangeable cations and cation exchange capacity (CEC)

Exchangeable Cations and Cation Exchange Capacity (CEC) were determined by ammonium acetate extractant (Bower et al, 1952). Five grams (5 g) of the soil sample were weighed and digested with 25 ml of 1.0 M sodium acetate and shake in a mechanical shaker for 5 minutes. The samples were centrifuged at 2000 rpm for 5 minutes and the supernatant was decanted. The decant was collected in a 100 ml volumetric flask fitted with a funnel and filter paper and was made up to the volume by adding ammonium acetate solution. The cations extracted from the soil by ammonium acetate were determined by flame photometer (Jackson 1973).

3.6.11 Total Exchangeable Bases

Total Exchangeable Bases (TEB) was determined by the summation of the Exchangeable cations. Exchangeable acidity consists of aluminum (Al^{3+}) and hydrogen (H^+). From the soil sample, exchangeable acidity was extracted with 1.0 M KCL, and the sum of Al + H^+ was determined by titration (McLean, 1965). Five grams of the soil sample was put into a bottle and 100 ml of 1.0 M KCL solution added. The mixture was shaken for one hour and then filtered. Fifty milliliters portion of the filtrate was transferred into anerlenmeyer flask and few drops of phenolphthalein indicator solution added. The solution was titrated with 0.05 N NaOH until the colour just turned permanently pink. The amount of base used was equivalent to total acidity (AL + H^+). A few drops of 0.05 N HCL were added to the same mixture to bring the solution back to colourless condition and 10 ml of ammonium fluoride (NaF) solution added. The solution was then titrated with 0.05 N HCL until the colour disappeared. The mill equivalent of acid used are equal to the amounts of exchangeable Al and the amount of

H was determined by difference.

Calculation was done using equation 14:

$$\text{Exchangeable Al} + \text{H or} \left(\frac{\text{cmol}}{kg}\right) = 0.05 \times V \times \frac{200}{W} \quad (14)$$

where: 0.05 = normality of NaOH or HCl used for titration

V = NaOH or HCl used for titration (ml)

W = air-dried soil sample weight in grams

3.6.12 Determination of Base Saturation

The base Saturation was calculated by dividing the total Exchangeable Bases by ECEC and the result expressed in percentage.

3.7 Planting and planting materials

In order to evaluate the effect of salinity on soil hydro-physical properties and the growth and yield of groundnut, a split plot based on Complete Block Design with four replications was carried out in a green house. The experimental factors were groundnut (Shitaochi and Manipinta) and the different levels of salinity solution with EC levels 0.0 dSm^{-1}, 2.0 dSm^{-1} 4.0 dSm^{-1} and 6.0 dSm^{-1} which is equivalent to 0.0, 1.27, 2.54 and 3.81 g/ml respectively. Seeds were obtained from Crop Research Institute, Fumesua, Kumasi-Ghana. In this study, four seeds were sown in each pot filled with 6.5 kg of bulk density. Primarily before sowing of seeds, the pots were irrigated with 1492.5 cm^3 of normal water. The pots were irrigated with the different salinity levels throughout the growing period of the crops at regular five (5) days intervals. The control pots were irrigated with normal water from the tap. At 14 days after germination, the plants were thinned to two and maintained in each pot to maturity.

3.8 Irrigation frequency

Based on the optimum mean annual rain of 1,300 mm in the transitional agro-ecological zone from where the soil samples were taken and minimum rainy days of 200 in the major rainy season, the moisture availability for groundnut (volume of water) to apply per day and per plant was calculated as follows:

Available moisture per day = 1,300/200 days

= 6.5 mm/day=0.65 cm/day

Depth of water (θz) 0.65 cm = volumetric water content $\times$ depth of soil But:

Depth of water (θz) = 0.65 cm

Volume of soil (volume of container) = $\pi r2\,h$

$= 3.142 \times 12^2 \times 20.3$

$= 9184.69\ cm^3$

Depth of soil = 20.0 cm

Therefore volume of water per day = $0.65\ cm \times 9184.69\ cm^3/20.0\ cm$

$= 298.50\ cm^3$

But initially to saturate the air-dried soil to field capacity, a five day volume of water was considered.

Thus:

Volume of water applied initially $=298.50\ cm^3 \times 5$

$= 1492.5\ cm^3$

An initial volume of 1492.5 cm^3 of water was applied to the soil in each pot and their individual masses were recorded. The pots were left for two days for the soil to equilibrate before sowing was done.

Sodium chloride solution concentrations of 1.27, 2.54 and 3.81 g/ml respectively, were formulated with the aid of conductivity meter (Corning type) and used to irrigate the crops. From the calibration curve, these corresponded to EC of 2, 4 and 6, respectively. These figures were used to establish the impact on crops when irrigation salt concentration exceeds the permissible value of 2.54 g/l. The crops were irrigated every five days and soil water content was monitored by weighing the pots prior to each irrigation and the mass was subtracted from the initial mass to give an estimate of the solution to be added. Plastic watering bottles were used to avoid addition of metals which could be the case if galvanized containers had been used. Fresh water from tap in the Institute campus, Kwadaso was used for the control experiment.

3.9 Germination studies

Germination tests were carried out on two layers of Whatman No.1filter papers in 9 mm diameter Petri dishes containing the two solutions. Batches of five seeds of each genotype were germinated in the Petri dishes, which were kept under plastic cover to reduce evaporation, and placed on the laboratory bench at room temperature (24-28 ^{0}C). The seeds were observed daily and the test solutions changed on alternate days and the percentage germination determined (ISTA, 1976).

3.10 Fertilizer application

To ensure adequate soil fertility throughout the experiment period, NPK (15:15:15) was added during irrigation at a rate of 0.05 g per plant in each of the experimental pots. The planted seeds were irrigated with the test solutions for the four treatments, replicated four times in a randomized split plot design with salinity as the sub- plots and genotypes as the main plots.

3.11 Determination of growth parameters

The following agronomic and physiological parameters were determined: plant height, number of leaves/plant, number of branches, number of flowers, and number of spikes per plant.

3.12 Criteria to asses salt tolerance

The ratio between the biomass produced under salinity to that of control was used to asses salt tolerance. After harvest, roots and stems were separated and dried to constant mass in a conventional oven at 70 ^{0}C. Manipinta, which was the second groundnut variety cultivated happened to be susceptible to salt in the different salt treatments, even though germination trial indicated that the seeds of Manipinta were viable, they failed to germinate with the levels of NaCl concentrations used. Therefore only the variety Shitaochi was used for the study.

3.12.1 Sodium content of the leaves:

Five grams (5 g) of dry finely ground leaf sample were digested in 35 ml of concentrated sulphuric acid with 0.5 % Selenium powder at 360 ^{0}C for 75 minutes on block digester and the digest was diluted to 75 ml for standard curve. Using this digest, Sodium was estimated for the different salt treatments using the Flame photometer (Gallenhamp model).

3.12.2 Relative water content

The third leaf of each selected plant was detached for Relative Water Content (RWC) determination. The detached leaf was immediately weighed and the measurement recorded as fresh mass (FW). The cut end of the leaf was placed in distilled water in a test tube; the tube was corked with cotton wool and kept under light condition in the laboratory. After 5 h, the leaves were removed, blotted dry and reweighed to obtain turgid mass (TW). The leaves were then dried over night at 80 ^{0}C and re-weighed to obtain the dry mass (DW). The relative water content (RWC was calculated using the following formular

$$RWC = \frac{(FW - DW)}{(TW - DW)} \times 100 \qquad (15)$$

where: RWC is the relative water content;

FW is the fresh mass (g);

DW is the dry mass (g);

TW is the turgid mass (g).

3.13 Yield parameters

Number of pods/plant, seeds/pod, seed/plant, and yield per plant were recorded

3.14 Soil parameters studied:

The following soil physical and hydrological properties were determined: Soil texture, moisture content, porosity, bulk density, gravimetric water content, volumetric water content, air-filled porosity, saturated hydraulic conductivity, infiltration and Electrical conductivity.

3.15.1 Soil texture

From the percentage of sand, silt and clay calculated, the textural triangle was used to determine the textural class of the soil.

3.15.2 Infiltration parameters:

After the end of the experiment, one sample each was taken and used to determine infiltration parameters. Using a constant head of 2 cm, ponded infiltration was measured in the pots. Graphs of cumulative infiltration amounts versus time were obtained. Sorptivity were obtained from plots of cumulative infiltration against square root of time for a period of five minutes. From the infiltration rate plots against time, the steady state infiltrabillity values were obtained.

3.15.3 Flux density of water:

When the soil became saturated, the volume of water that outflowed for five minutes was determined for each sample at a constant head of 2cm. The volume of water that outflowed was collected in a bucket and later measured with a measuring cylinder. The flux was calculated as volume of outflow divided by the time used (m^3h^{-1}).

3.15.4 Bulk density, porosity and air-filled porosity and Electrical Conductivity after the experiment

After the experiment, soils from the different treatments were sampled to determine bulk density, porosity and air-filled porosity. The auger was inserted into the experimental pots by applying a downward force while rotating it, and it filled as it went deeper into the soil. Once filled at the correct depth, it was removed and the soil placed into a clean dry container and labeled. The auger was periodically cleaned between each sample taken to avoid contamination. The EC of the soil samples were measured on the saturation extracts with an EC Conductivity meter.

(a) The bulk density was calculated using the following formula:

$$pb = \frac{Ms}{Vt} \qquad (16)$$

where Pb = bulk density of soil;

ms = oven dry mass of soil; vt = total volume of soil

(b) Porosity (F) was calculated as:

$$f = \left(1 - \frac{Pb}{ps}\right) \qquad (17)$$

where Pb = bulk density; ps = particle density (2.65g cm^{-3})

(c) Air-filled porosity was calculated using the following formula;

$$As = f - \theta_v \quad (18)$$

where: As = air-filled porosity;

θ_v = volumetric water content

3.15.5 Evapotranspiration (ET)

Soil water was monitored by weighing the pots prior to irrigation and subtracting the mass from the initial (previous) mass to give an estimate of evapotranspiration and hence the amount of water to be replaced. The total amount of water obtained during the experimental period gave the ET of the crop. (Plate 5)

Plate 4: Weighing of samples prior to irrigation.

3.16 Statistical package:

Data obtained was subjected to statistical analysis using Analysis of Variance (ANOVA) and means were separated using Least Significant Difference (LSD) at 5 % level of probability. GenStat statistical package was used.

CHAPTER FOUR

4.0 RESULTS

In this chapter, the results of different salinity levels on some soil chemical, physical and hydrologic properties are presented. As a check, the initial chemical properties of the soil used are presented. Also, the effects of salinity levels on groundnut growth and yield are presented.

Table 4.1 a. Initial and final soil properties.

pH	Org.C (%)	Total N (%)	Org.M(%)	Exchangeable cations cmol/kg				TEB	Based sat. (%)
				Ca	Mg	K	Na		
6.0	2.2	0.3	3.8	5.6	2.7	0.1	0.1	8.4	97.1

Table 4.1 b. Initial properties continued

Exchangeable Acidity (Al+H)	ECEC cmol/kg	Available P (ppm)	Available K (ppm)	Soil texture (%)			Textural class
				Sand	Silt	Clay	
0.3	8.7	10.5	110.5	67.7	28.2	4.0	Sandy loam

4.1 Initial chemical properties of the soil

The initial properties of the soil used for the greenhouse studies are shown in Table 4.1 (a and b). The texture of the soil was sandy loam. The initial soil reaction was moderately acidic with low nitrogen and phosphorus content. Potassium and sodium were the most deficient exchangeable cations. The base saturation of the initial sample was 97.10 %.

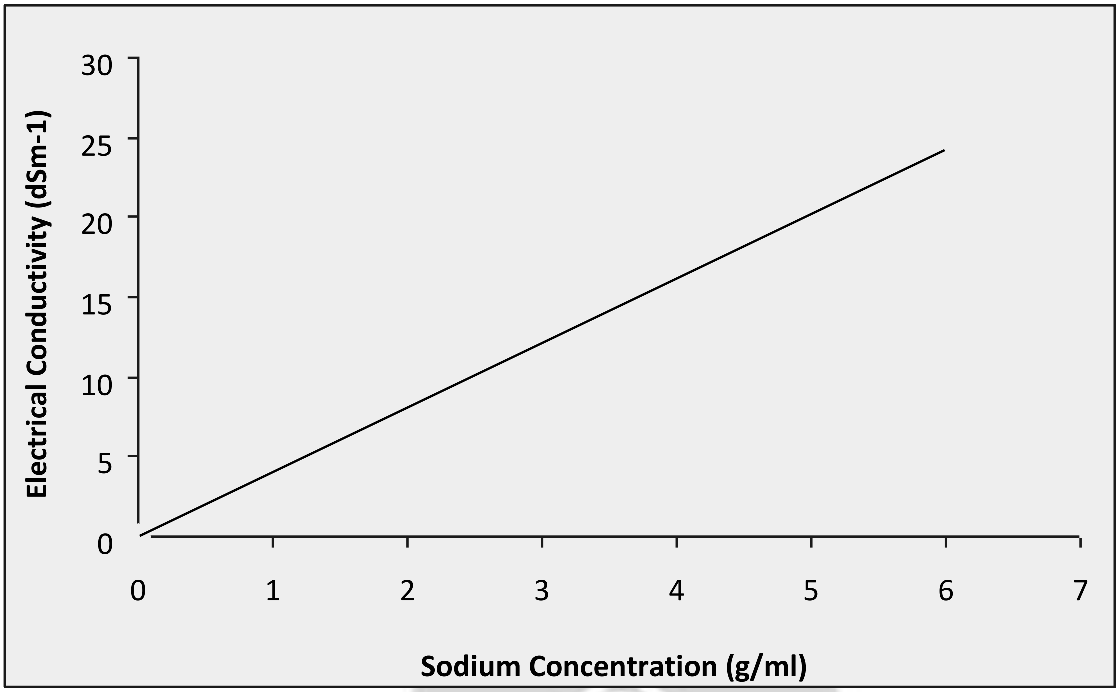

Figure 1.0: Calibration of EC against NaCl

There was a linear relationship between EC and Sodium chloride concentration. This relationship was used to select NaCl concentrations that corresponded with Ec 2, Ec 4 and Ec 6.

4.2 The final chemical properties of the soil

Table 4.2 a. Final soil properties

EC dSm^{-1}	pH H_2O	Org.C (%)	Total N (%)	Org.M (%)	changeable ca cmol/kg				TEB	Based sat. (%)
					Ca	Mg	K	Na		
0.0	5.4	2.3	0.2	3.9	4.0	1.6	0.5	0.3	6.4	92.8
2.0	5.0	2.3	0.2	4.2	4.3	2.1	1.2	4.6	12.2	94.6
4.0	5.1	2.1	0.2	3.6	4.5	2.0	1.4	3.5	11.	95.2
6.0	5.5	2.2	0.1	3.8	4.0	1.5	1.3	3.5	10.3	101.0

Table 4.2 b. Final soil chemical properties continued

EC dSm^{-1}	Exchangeable A.(Al+H)	ECEC cmol/kg	Available P (ppm)	Available K (ppm)
0.0	0.6	6.9	112.4	133.9
2.0	0.7	12.9	194.5	247.7
4.0	0.6	12.1	61.4	277.9
6.0	0.5	10.2	134.7	247.7

At the end of the experiment, some chemical properties of the soil taken from the 0-15 cm depth in the pots were determined and their values are given in Table 4.2 (a and b). The treatments caused further decrease in the soil pH, total nitrogen, exchangeable calcium and magnesium and base saturation. At the end of the experiment, exchangeable potassium and sodium increased. Also, exchangeable acidity and effective cation exchange capacity increased with increasing salinity levels. The available phosphorus and potassium increased at the end of the experiment.

4.3 Effect of salinity levels on some soil physical properties

Table 4.3: Effect on some hydrologic properties:

Parameter	Salinity nduced as EC (dS n-1)			
	0.0	2.0	4.0	6.0
Bulk density (g cm^{3})	1.3	1.3	1.4	1.3
Porosity (%)	52.2	52.2	48.8	48.7
Volumetric water content (%)	33.1	33.1	37.9	35.8
Air-filled porosity (%)	19.1	19.1	10.8	12.9

4.3.1 Effect on bulk density and porosity

Initially all the pots were packed with soil to an approximate bulk density of 1.3 g cm^{-3}.

At the end of the experiment, the bulk densities of the high salinity levels (EC 4 and EC 6) had increased by 7 % while porosity had similarly decreased by 7 % (Table 4.3). Analysis of variance showed that salinity did not bring about any significant change in bulk density and porosity (Appendices 1 and 2).

4.3.2 Effect on soil water content and air-filled porosity

Even though during irrigation, the potted plants were irrigated to the same initial water content, at the end of the experiment, the high salinity levels (EC 4 and EC 6) contained 14.5 % water and 8.2 % water by volume more than the control and the EC 2 treatments (Table 4.3). Thus, there was an apparent increase in soil moisture as salinity increased. The implication is that the ability of the plants to take up water from the soil decreased as salinity increased. Nevertheless, the analysis of variance showed no significant difference in soil moisture content at the end of the experiment for the different salinity treatments (Appendix 3).

As expected, air-filled porosity decreased as the salinity level increased. (Table 4.3). Similarly the analysis of variance indicated that there was no significant difference in air-filled porosity with different salinity levels (Appendix 4).

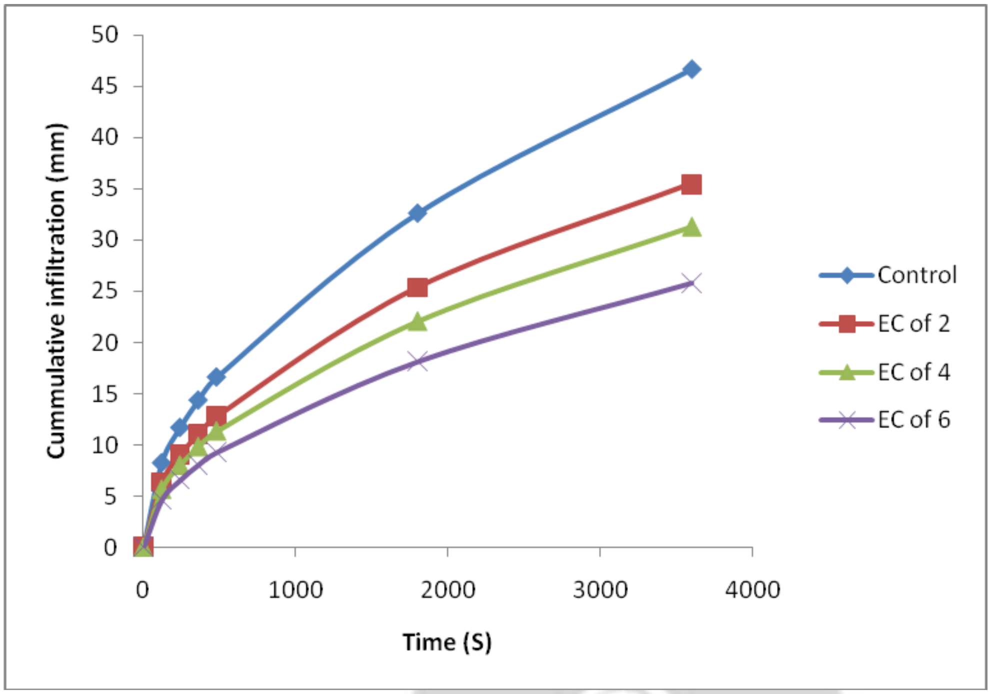

Figure 2: Cumulative infiltration as a function of time

4.4 Effect of treatments on water infiltration

Plots of cumulative infiltration as a function of time for the control (EC 0) and treatment EC 2, EC 4 and EC 6 are given in Fig. 2. The plots indicated that there was a drastic reduction on the ability of the soil to allow water to enter. As salinity levels increased, the ability of the soil to admit water further decreased. Using the equation

$I = St^{1/2} + K_0t$, apparent hydraulic conductivity and sorptivity were calculated.

Table 4.4: Sorptivity (S) values and hydraulic conductivity (Ks) after treatments

(ECdSm^{-1})	Apparent hydraulic conductivity (cm s^{-1})	Sorptivity (mm s$^{-1/2}$)
0.0	5.16 $*10^{-3}$	0.8
2.0	2.06 $*10^{-3}$	0.6
4.0	8.84 $*10^{-4}$	0.5
6.0	1.47 $*10^{-3}$	0.4

The infiltration parameters (sorptivity and apparent hydraulic conductivity) calculated from the infiltration measurements are given in Table 4.4. Sorptivity is the ability of the soil to absorb water by capillarity. These hydraulic properties decreased as salinity increased. The hydraulic conductivity decreased by 60 % at salinity level with EC 2 dSm^{-1}, 82.9 % at salinity level with EC 4 dSm^{-1} and 71.5 % at salinity level with EC 6 dSm^{-1}.

4.4.1 Effect of treatments on evapotranspiration (ET)

The evapotranspiration of groundnut at different salinity levels was estimated as the difference between the total amount of irrigation water and the water content of the soil at the end of the experiment. The estimated ET values are given in (Table 4.5). The study showed that ET of groundnut decreased as salinity levels increased.

Table 4.5: Effects of salinity on evapotranspiration Treatment EC dSm^{-1} Amount of water used per pot (ccl)

0	9.8	8.1	6.8	4.2	2
9.7	7.9	7.3	6.8	4	
10.7	9.5	7.6	8.3	6	
12.4	9.9	8.3	9.5		

The implication is that the ability of the groundnut to withdraw water from the soil decreased as salinity level increased. The analysis of variance showing the effect of the treatments on ET is shown in (Table 4. 5). The analysis of variance showed that there was a significant difference in ET of groundnut for the different treatments at 5 % level of probability.

Table 4.6: Analysis of variance table for the effect of different salinity levels on evapotranspiration

Sources of variance	Df	ss	ms	F
Treatment	3	29.700	9.900	0.020**
Residual	12	24.520	2.043	
Total	15	54.220		

Standard errors of differences of means (SED)	1.011
Least Significance Difference of means (LSD) at 5 % level	2.202
Coefficient of variation (CV) (%)	16.7

** Significant at 5% level.

4.5 EC of treatments at the end of the experiment

EC before the experiment (dSm^{-1})	EC after the experiment (dSm^{-1})
0.0 2.0	0.0
4.0	5.5
6.0	8.4
	7.5

4.5.1 The EC values at the end of the experiment

The EC values increased drastically with increase in salinity level of irrigation water applied. In the treatment pots irrigated with fresh water, EC values remained zero. Maximum value of EC which was 6.0 dSm^{-1} had increased to 7.54. In the other treatments, the EC 4 treatment had increased to 8.44, whereas the EC 2 had gone up to 5.54. This demonstrates that addition of salt has cumulative effect on salinity (Table

4.7).

4.6 Effect of treatments on plant parameters

Table 4.6: Effects of salinity on germination and seedling development of groundnut cultivar (Shitaochi)

Parameter	Salinity induced as EC (dSm^{-1})			
	0.0	2.0	4.0	6.0
Germination (%)	100	100	75	50
Mean plant height (cm)	76.5	58.7	53.2	49.2
Mean number of branches	4.5	3.8	3.25	2.3
Mean number of leaves	48.2	40.5	34.0	33.5

The percentage germination of groundnut, the mean plant height, the mean number of branches and mean number of leaves of groundnut are shown in (Table 4.6). The results showed that germination, plant height number of branches and number of leaves all decreased as salinity level increased. The threshold salinity for hundred percent germination for groundnut was 2.0 dSm^{-1}. Beyond EC of 2.0, germination decreased by 25 % and 50 % for EC 4 dSm^{-1} and EC 6 dSm^{-1} respectively (Table 4.6). The reduction in plant height was more pronounced at EC 6 dSm^{-1}. Salinization with EC 2 dSm^{-1} did not have any significant effect on the number of branches. The effect of salt stress on the number of leaves was similar to that of number of branches.

Analysis of variance showed that there were significant decreases in plant height, number of branches and number of leaves with salinity at 5 % probability levels (Tables 4.6, 4.7, and 4.8).

Table 4.7: Analysis of variance table for the effect of different salinity levels on plant height

Sources of variance	Df	ss	ms	F
Treatment	3	1746.44	582.15	<001**
Residual	12	276.87	23.07	
Total	15	2023.31		

Standard errors of differences of means (SED)	3.40
Least Significance Difference of means (LSD) at 5 % level	7.40
Coefficient of variation (CV) (%)	8.10

Table 4.8: Analysis of variance table for the effect of different salinity levels on number of branches

Sources of variance	Df	ss	ms	F
Treatment	3	10.6875	3.5625	>001**
Residual	12	3.2500	0.2708	
Total	15	13.9375		

Standard errors of differences of means (SED)	0.368
Least Significance Difference of means (LSD) at 5 % level	0.802
Coefficient of variation (CV) (%)	15.1

Table 4.9: Analysis of variance table for the effect of different salinity levels on number of leaves

Sources of variance	Df	ss	ms	F
Treatment	3	572.19	190.73	0.001**
Residual	12	218.75	18.23	
Total	15	790.94		

Standard errors of differences of means (SED)	3.02
Least Significances Difference of means (LSD) at 5 % level	6.58
Coefficient of variation (CV) (%)	10.9

Table 4.10: Effects of salinity on some physiological and yield parameters of groundnut (Shitaochi)

Parameter	**Salinity induced as EC (dSm^{-1})**			
	0.0	2.0	4.0	6.0
Mean dry matter of vegetative part (g)	49.8	23.7	9.4	12.7
Mean relative water content (%)	7.3	7.0	5.3	5.2
Mean sodium concentration in leaves (%)	0.4	0.6	0.2	0.7
Mean number of flowers	37.2	29.2	23.8	21.8
Mean number of spikes	12.0	7.3	4.8	3.0
Mean number of pods/plant	14.3	10.3	5.5	4.5
Mean number of seeds/plant	28.5	20.5	11.0	9.0
Mean yield/plant (kg/ha^{-1})d	25.0	16.3	2.8	0.0

4.7 Effect of salinity on some physiological and yield parameters

The effect of different levels of salinity on plant biomass, relative water content, sodium concentration in leaves, mean number of flowers per plant, mean number of spikes per plant, mean number of pods per plant, mean number of seeds per plant and mean yield per plant are presented in (Table 4.10).

The biomass of the plant decreased between 52.6 % and 81.8 % as salinity increased from 2.0 dSm^{-1} to 6.0 dSm^{-1}. Salinity stress did not affect root dry mass (Fig.5). No increase was observed when plants were salinized with the highest NaCl concentrations. Salinity stress decreased stem dry mass with the greatest obtained when plants were salinized to EC 2 dSm^{-1}. Between EC 2 and EC 6 dSm^{-1}, stem dry mass was not strongly affected (Fig 3). The mean plant height, the number of branches, number of leaves, number of flowers, number of spikes, number of pods per plant number of seeds per plant and yield per plant significantly decreased at 5 % probability level (Table4.114.15). At the highest NaCl concentration, the plants were more affected. It is well known that salinity reduces plant growth and that there are differences in tolerance to salinity among species and among cultivars.

Table 4.11: Analysis of variance table for the effect of different salinity levels on number of flowers

Sources of variance	Df	ss	ms	F
Treatment	3	577.00	192.33	0.012**
Residual	12	409.00	34.08	
Total	15	986.00		

Standard errors of differences of means (SED) 4.13

Least Significance Difference of means (LSD) at 5 % level 8.99

Coefficient of variation (CV) (%) 20.9

Table 4.12: Analysis of variance table for the effect of different salinity levels on number of spikes

Sources of variance	Df	ss	ms	F
Treatment	3	183.500	61.167	0.001**
Residual	12	71.500	5.958	
Total	15	255.000		

Standard errors of differences of means (SED) 1.726

Least Significance Difference of means (LSD) at 5 % level 3.761

Coefficient of variation (CV) (%) 36.2

Table 4.13: Analysis of variance table for the effect of different salinity levels on number of pods/plant

Sources of variance	Df	ss	ms	F
Treatment	3	244.250	81.417	>001**
Residual	12	81.500	6.792	
Total	15	325.750		

Standard errors of differences of means (SED) 1.843

Least Significance Difference of means (LSD) at 5 % level 4.015

Coefficient of variation (CV) (%) 30.2

Table 4.14: Analysis of variance table for the effect of different salinity levels on number of seeds/plant

Sources of variance	Df	ss	ms	F
Treatment	3	977.00	325.67	>001**
Residual	12	326.00	27.17	
Total	15	1303.00		

Standard errors of differences of means (SED)	3.69
Least Significance Difference of means (LSD) at 5 % level	8.03
Coefficient of variation (CV) (%)	30.2

Table 4.15: Analysis of variance table for the effect of different salinity levels on yield/plant

Sources of variance	Df	ss	ms	F
Treatment	3	1650.50	550.17	>001**
Residual	12	171.50	14.29	
Total	15	1822.00		

Standard errors of differences of means (SED)	2.673
Least Significance Difference of means (LSD) at 5 % level	5.824
Coefficient of variation (CV) (%)	34.4

The relative water content of the leaves also significantly decreased as the salinity level increased (Appendix 5). On the contrary, sodium content of the leaves increased by 33.3%, when the salinity was increased to 2.0 dSm^{-1}, 80.0 %, when the salinity was increased to 4.0 dSm^{-1} and 94.6 % when the salinity was further increased to 6.0 dSm^{-1}. The corresponding yield reductions were 35 %, 89 % and 100% for 2.0 dSm^{-1}, 4.0 dSm^{1} and 6.0 dSm^{-1} salinity levels, respectively.

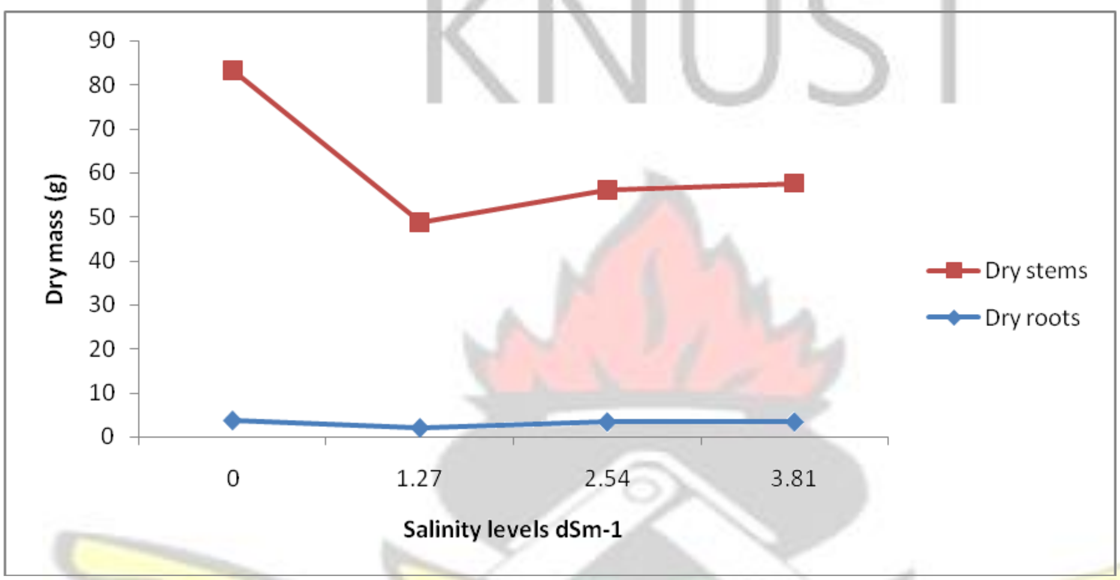

Figure 3: Effect of salinity levels on dry roots and stems

CHAPTER FIVE

5.0 DISCUSSIONS

In this chapter, the results of the studies are discussed with reference to the effects of induced salinity levels on the changes in the physical, chemical and hydrologic properties of the soil. The influence of induced salinity levels on the performance of groundnut is discussed with respect to growth factors and yield. The cumulative application of sodium chloride and its consequences on sodium accumulation in the plant and the final electrical conductivity of the soil are further discussed.

5.1 Effect of induced salinity levels on the physical and chemical properties of the soil

5.1.1 Bulk density and total porosity

The results showed that bulk density increased and porosity decreased as salinity levels increased. The high sodium content might have caused dispersion of clay particles leading to sealing of pores and formation of dense layer in the soil. Large suction forces have been observed to form between the soil-crust interfaces by Frenkel *et al.*, (1978); Shainberg and Letey (1984). The dispersed clay has the ability to clog soil pores leading to the development of suction forces. Soil structure degradation due to addition of sodium chloride is common knowledge.

5.1.2 Soil pH and exchangeable acidity

The soil pH value at the beginning of the study was 6.0. This value had dropped for all the treatments at the end of the experiment. The addition of sodium should cause an increase in the pH value, but these results showed. The drop in pH values could be due to addition of nitrogen fertilizer to all the treatments including the zero salinity level. The addition of nitrogen fertilizer further explains the increase in the exchangeable acidity. This finding is in consistence with those reported through several studies
(Narwel *et al*., 1993; Singh and Verloo 1996).

5.1.3 Potassium and Phosphorus

At the end of the experiment, it was observed that available potassium and phosphorus concentrations had increased with salinity levels. Potassium and phosphorus were also added to all the treatments as fertilizers. Increasing salinity prohibited water and nutrient uptake. Hence, nutrient accumulation in the soil increased with increasing salinity levels. Similar observations were reported by Pescod (1992), Emongor and Ramolemana (2004), and Heidarpour *et al*., (2007).

5.1.4 Electrical conductivity of soil

At the end of the experiment, the EC values of the different salinity levels increased. The increase in EC was due to cumulative input of salt from induced salinity. Similar results had been described by Gil and Ulloa (1997), Xanthoulis and Kayamanidou (1998) and Massena (2001). There was an increase in EC values in the upper soil layer during the study period. This was due to an upward movement of water from evaporation, which resulted in an accumulation of salts at the soil surface. This result is in agreement with similar findings by Choi and Suarez (2004), Assadian *et al*., (2005), Al-Zu'bi (2007) and Heidarpour *et al*., (2007).

5.2 Effect of induced salinity of hydrologic soil properties.

Infiltration rate decreased as the levels of salinity increased. Also, the infiltration parameter in the form of sorptivity and apparent hydraulic conductivity all decreased as salinity levels increased. The cumulative addition of sodium chloride in the irrigation water increased the salinity levels to the point at which the soil structure was completely destroyed. The dispersed soil particles due to the addition of sodium salt caused the soil pore to get clogged, resulting in decreased water infiltration.

If water cannot pass through the soil, then the upper layer can become waterlogged resulting in excessive runoff generation. This results in anaerobic soils.

5.2.1 Evapotranspiration (ET)

The estimated ET values in Table 4.6 showed that increasing salinity level of irrigation water decreased evapotranspiration compared to irrigation with tap water. This may be interpreted that increasing salinity of irrigation water increased tensions which water is held by soil and a relative slow rate of water conductivity through the soil compared to the great evaporative power of the atmosphere.

Similar decreases with increasing salinity were recorded by Ashraf (2001) with Brassica species. Bassil and Kaffka (2002) observed that consumptive water use and total biomass declined at high EC and that safflower‘s evaporative demand was correlated with reduced height and leaf area in saline pots.

Reduction in water uptake has also been related to reduction in hydraulic conductance of the root system (Rodriguez *et al*., 1997). This may explain the reduction in water absorption rate and may contribute to a similar reduction in nutrient uptake resulting in decreased dry-matter yield under salt stressed conditions.

Similarly, it can be inferred that there was significant reduction of gaseous exchange in the salt treated pots which were proportional to the increase in NaCl level. Similar results were reported by Ashraf (2001) with Brassica species where both photosynthetic and stomata conductance showed significant decreasing trends with increase in salt concentration in the rooting medium. Similarly, Bayuelo-Jimenez *et al*., (2003) reported a reduction in photosynthetic carbon assimilation in Phaseolus species and attributed this decrease to reduced stomata conductance.

Reduction in net carbon dioxide assimilation by increased salinity could be due to a limitation of carbon dioxide supply as a result of stomata closure (Perera *et al*., 1994; Stedulo *et al*., 2000); to non stomatal factors related to toxic effect of salts in the activity of the photosynthetic mesophyll thus depressing specific metabolic processes in carbon uptake (Seeman and Critchly, 1985; Sultana *et al*., 1999; Chen *et al*., 1999); inhibition in photochemical capacity or a combination of these factors (Everard *et al*.,1994; Dubey, 1997). Meloni *et al*., (2003) also reported that the stomata closure limited leaf photosynthetic capacity in the NaCl treated cotton plants.

5.3 Effect of salinity on germination and seedling development of groundnut Shitaochi

5.3.1 Seed germination

The results obtained from the germination studies show that groundnut genotype Shitaochi responded differentially to the different levels of salinity. As the level of salinity increased, there were corresponding decreases in the percentage germination and seedling emergence. The most effective concentration, which depressed the germination counts, was saline solution with electrical conductivity of 6.0 dSm^{-1}. The cultivar recorded the highest percentage germination in the control experiment. The ability of a seed to germinate and emerge under salt stress indicates that it has genetic potential for salt tolerance (Tejovathi *et al*., 1988). The trends observed in the germination and shoot emergence studies as well as numbers of leaves determinations indicated that, increasing salinity led to reductions in the value of the specific parameter under study. The present observations are in line with earlier reports for wheat (Hurd, 1974), goat weed (Singh and Jain, 1989), sorghum (Sullivan and Ross, 1979) and chickpea (Al-Mutawa, 2003), where increases in salinity also led to decreased radicle lengths.

5.3.2 Seedling development

Salinity stress caused reduction in plant height in all the treatments with the exception of the control although the relative effects varied. The least mean plant height was recorded under higher saline solutions. There were no significant difference on the number of branches at EC 0 but as salinity increased, there were significant difference at LSD of 5 %. The same trend was seen on the number of leaves, number of flowers and number of spikes, respectively as shown in appendices 7, 8, 9, and 10.

Salinity became a problem when enough salts accumulated in the root zone and negatively affected plant growth. Excess salts in the root zone hindered plant roots from withdrawing water from surrounding soil. This lowered the amount of water available to the plant, regardless of the amount of water actually in the root zone. For example, when plant growth is compared in two identical soils with the same moisture levels, one soil receiving salty water and the other receiving salt-free water, plants are able to use more water from the soil receiving salt-free water. Although the water is not held tightly to the soil in saline environments, the presence of salt in the water causes plants to exert more energy in order to extract water from the soil. The main point is that excess salinity in soil water decreases plant available water and causes water stress in plants.

It is well known that salinity reduces plant growth and that there are differences in tolerance to salinity among species and cultivars (Cruz *et al*., 1990; Bolarin *et al*., 1991; Romero-Aranda *et al*., 2001). Ashraf (2001) recorded a significant reduction in mean fresh and dry mass of shoots of Brassica species with increase in salinity concentration and observed that the response to salinity stress differed with species and the measured growth variables. Furthermore, there was a decrease in the mean number of leaves per plant with an increase in the salt concentration. The result agrees with the report of Akomeah *et al*., (1991) in Machaerium lunatus where it was observed that low salinity of 1 % seawater (with electrical conductivity of about 0.05 dSm^{-1}) enhanced the production of leaves compared to plants irrigated with higher saline solutions.

5.4 Effect of salinity on some physiological and yield parameters of groundnut Shitaochi

5.4.1 Dry matter

Generally, at high saline concentrations (4-6 dSm^{-1}), the dry matter of the groundnut genotype under study decreased. The dry mass of shoot and root expressed as percentage of the control for each treatment was significantly reduced by salinity stress. The dry matter results are in agreement with the work of Hassan et al. (1970) for Barley, and Al-Mutawa (2003) for chickpea, in which the authors observed that high saline concentrations decreased the dry mass of the affected crops. Salinity stress did not affect root dry mass. No increase was noted when plants were salinized with higher NaCl concentrations. Salinity, however, decreased shoot dry mass with the greatest reduction obtained when plants were salinized at EC 2 dSm^{-1} to EC 6 dSm^{-1}. Stem dry mass was affected by salinity

Available literature (Hurd, 1974; Singh and Jain, 1989 and Abdul-Halim *et al*., 1988) indicates that under salinity stress, plants tend to record low yields because of adverse effects of salinity on such parameters as relative water content, total dry mass, plant height and number of leaves per plant. This is because salinity inhibits plant growth by exerting low water potentials, ion toxicity and ion imbalance (Greenway and Munns, 1980; Sharma, 1997). Mums (2003) stated that suppression of plant growth under saline conditions may either be due to decreasing the availability to water or increasing NaCl toxicity associated with increasing salinity.

The response of growth to salinity stress in relation to shoot growth differed. A high root dry mass could indicate an increased capacity of water uptake, thereby maintaining the shoot in a well hydrated condition (Blum, 1996). A reduction in root growth with increasing root zone salinity was also observed by Bassil and Kaffka (2002) with safflower. According to Bassil and Kaffka (2002) earlier physiological maturity could have accounted for some of the observed reduction in root growth of safflower grown in saline pots. The result in this study is in line with observations from most investigators who found that roots were less affected by salinity than shoots (Brugnoli and Bjorkman, 1992; Chartzoulakis *et al*., 1995; Perez-Alfocea *et al*., 1996). Fisarakis *et al*., (2001) reported that at 50 nM and especially at 100 nM NaCl concentration, root growth of sultana was less affected than that of shoots resulting in high root/shoot ratios. Munns (2002) pointed out that under certain condition high root/shoot ratio may actually enhance the accumulation of toxic ions in the shoot. De Pascale *et al*., (2003a) proposed that the smaller root/shoot ratio observed in salinized versus drought affected plants may be functionally associated with the need of salt stressed plants to restrict the uptake of toxic ions to the shoot while still maintaining high turgor and a positive growth rate.

According to Gunes *et al*., (1996); Shen *et al*., (1997) and Maggio *et al*., (2001)this may be accompanied by simultaneously reducing root as well as shoot development and activating specific metabolic pathway which occurs in saline environment.

The relative water contents of the leaves of the groundnut genotype decreased with increase in salinity except in treatment four, which showed increase in relative water content with increased salinity. This observation agrees with the earlier reports of Rathert (1984) who reported that plants which are stressed by salinity accumulate starch and soluble carbohydrates in their leaves.

5.4.2 Soil sodium concentrations in leaves

In the initial soil samples, sodium (Na) concentrations were 0.05 me/100g. An appreciable increase in concentrations of Na was found in all the treatments except the control and treatment with EC of 2 dSm^{-1}, as previously described by Bredai (1996). The significant increase in Na concentrations in the soil may be related directly to a high concentration of soluble salts in the saline water. Similar results were shown by Lazarova (1999). The highest Na concentrations were found at EC 6. Similar findings are reported elsewhere (Johnson *et al*., 1989, Tedeschi and Dell'Aquila 2006). Obviously, the rate of salt accumulation in plants changes with time and accumulations of Na increases at high levels of soil salinization (Schofield *et al*., 2001).

In most plants, the accumulation of Na in shoot brings about deleterious effect, and the plant strategy is to limit the Na build-up in the shoot tissues. Although it was found that the Na concentration in shoot decreased with the highest salt treatment. It had been reported that increases in salinity reduced yield, decreased leaf water potential and caused loss of turgidity and available water in plant cells (Munns 2002, Neuman 1997).
Salinity caused loss of turgidity in plants which adversely affected plant development (Munns 2002). Poljakoff-Mayber and Lerner (1999) also confirmed that salinity negatively affected cell growth, generated smaller leaves, consequently resulted in reduction of photosynthesis and dry matter yield. There was no relationship between the shoot Na concentration and the relative sensitivity of plants to salt treatment.

5.4.3 Flowers and pod yield

Negative effects of salinity on plant growth had direct effect on ultimate plant productivity (number of flowers, spikes, pod nut) (Table 4. 7). Salinity reduced the number of flowers and pods per plant in Shitaochi groundnut. Salinity levels at EC 4 and EC 6 had the least flower and pod production compared to the control and other saline condition, (Table 4.

7). Hayat *et al*., (2001) reported that salinity reduced the number of flowers and pods in six chickpea genotypes.

Also the results really showed that seed number was drastically affected by salinity at all levels. With increase in salt concentration from 0.00 dSm^{-1} to 6.0 dSm^{-1}, there was a sharp decrease in seed number. This reduction was more pronounced at levels 4 dSm^{-1} and 6 dSm^{-1} in comparison to the control. The main reason for this reduction could be attributed to decrease in photosynthesis, nitrogen metabolism and carbon metabolism under saline conditions (Tejera *et al.*, 2006).

Yields were negatively affected by salinity in all levels, so that increasing salt concentration decreased yield of the cultivar. Sadiki and Rabih (2001) stated that salinity reduced yield by 26 to 38 % according to genotypes. Salinity drastically reduced photosynthesis (Seeman and Sharkey, 1986; Soussi *et al*., 1998), nitrogen metabolism (Cordovilla *et al*., 1995; Mansour, 2000), carbon metabolism (Delgado *et al*., 1994; Soussi *et al*., 1999; Balibrea *et al*., 2000) and promotes disorders in plant nutrition which may lead to deficiencies of several nutrients and high levels of Sodium.

Anand *et al*., (2000) found that photosynthesis in two alfalfa genotypes was higher when plants were watered with tap water compared to water having EC of 4 dS m^{-1} water containing chloride and sulphate salts. They reported that certain doses of salts might induce photosynthesis, hence, plant growth.

The result showed that decrease in yield was more severe at salinity level of 6 dSm^{-1} compared to other treatments. The highest yield averaging 25.00 g per plant was obtained from the treatment pots irrigated with fresh water. Increasing irrigation water salinity increased salt concentration and osmotic potential in the root zone. However, due to the nature of irrigation, frequent water applications maintained the soil water content in the root zone in the nearest 50 % of the available water thus reducing the effect of osmotic potential on water uptake.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Saline water deleteriously affects the physical and hydrologic properties of the soil. The increase in bulk density and decreased infiltrabillity of the soil with salinity indicate that in the field, salinity can lead to serious soil degradation problems.

Salinity increased exchangeable potassium and calcium, exchangeable acidty and effective cation exchange with increasing salinity levels.

Salinity reduced the number of flowers and pods per plant in groundnut and the seed number was drastically reduced as salinity increased. Yields were negatively affected by salinity in all levels, but the effects were more pronounced at salinity level of EC 6. The salinity limit for groundnut production with respect to the variety used is between 0 and 2.0 dSm^{-1} beyond which growth and yield of the groundnut variety used are drastically reduced.

Increased salinity caused an appreciable increase of sodium chloride concentration in groundnut leaves.

Increased in salinity resulted in increased Electrical conductivity and vice- versa. The inhibitory effect of water uptake by plants with increased salinity suggests that salinity can seriously induce soil fertility problems in the field.

6.2 Recommendations

It is recommended that chemical changes in the rooting zone of irrigated crops must be carefully monitored to ascertain if salinity is incipient.

Further work is needed to screen different genotypes of groundnut for their tolerance to salinity.

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APPENDICES

Appendix 1: Analysis of variance table for the effect of different salinity levels on porosity

Sources of variance	Df	ss	ms	F
Treatment	3	47.49	15.83	0.535 ns
Residual	12	248.36	20.70	
Total	15	295.85		

Standard errors of difference of means (SED) 2.27

Least Significance Difference of means (LSD) at 5 % level 7.01

Coefficient of variation (CV) (%) 9.0

Appendix 2: Analysis of variance table for the effect of different salinity levels on bulk density

Sources of variance	Df	ss	ms	F
Treatment	3	0.03332	0.01111	0.5386 ns
Residual	12	0.17442	0.01454	
Total	15	0.20774		

Standard errors of difference of means (SED) 0.0853

Least Significance Difference of means (LSD) at 5 % level	0.1857
Coefficient of variation (CV) (%)	9.2

Appendix 3: Analysis of variance table for the effect of different salinity levels on volumetric water content

Sources of variance	Df	ss	ms	F	
Treatment	3	66.34	22.11	0.761	ns
Residual	12	677.22	56.43		
Total	15	743.56			

Standard errors of differences of means (SED)	5.31
Least Significance Difference of means (LSD) at 5 % level	11.57
Coefficient of variation (CV) (%)	21.50

Appendix 4: Analysis of variance table for the effect of different salinity levels on air-filled porosity

Sources of variance	Df	ss	ms	F	
Treatment	3	217.0	72.3	0.639	ns
Residual	12	1497.2	124.8		
Total	15	1714.2			

Standard errors of differences of means (SED)	7.90

Least Significance Difference of means (LSD) at 5 % level 17.21

Coefficient of variation (CV) (%) 72.20

Appendix 5: Analysis of variance table for the effect of different salinity levels on relative water content

Sources of variance	Df	ss	ms	F
Treatment	3	402.9	134.3	0.499**
Residual	12	1952.6	160.5	
Total	15	2328.4		

Standard errors of differences of means (SED) 8.96

Least Significance Difference of means (LSD) at 5 % level 19.52

Coefficient of variation (CV) (%)

Appendix 6: Daily Relative Humidity and temperatures during the study period

Date	July-09			
	Morning (9.00 am)		Afternoon (3.00 pm)	
	Temperature (ºC)	Relative Humidity (%)	Temperature (ºC)	Relative Humidity (%)
2-Jul-09	28	85	32	68
3-Jul-09	30	85	35	69
4-Jul-09	29	81	33	76
5-Jul-09	29	89	33	73
6-Jul-09	29	89	34	70.5
7-Jul-09	27	91	33	72
8-Jul-09	29	86	26	92.5
9-Jul-09	29	88	32	76
10-Jul-09	29	87	30	82
11-Jul-09	26	94	27	88
12-Jul-09	28	89	30	84
13-Jul-09	26	90	29	82
14-Jul-09	27	93	30	81
15-Jul-09	27	88	32	71
16-Jul-09	27	89	30	73
17-Jul-09	26	94	30	81

18-Jul-09	27	93	30	72
19-Jul-09	26	92	30	69
20-Jul-09	28	89	34	66
21-Jul-09	29	89	30	56
22-Jul-09	27	92	30	83
23-Jul-09	27	94	31	72
24-Jul-09	28	91	32	72
25-Jul-09	28	90	31	86
26-Jul-09	26	90	29	88
27-Jul-09	29	86	30	76
28-Jul-09	26	92	29	84
29-Jul-09	26	92	30	78
30-Jul-09	27	87.5	30	83
31-Jul-09	27	94.5	30	81
Mean	27.57	89.67	30.73	76.83

Date	August-09			
	Morning (9.00 am		Afternoon (3.00 p	
	Temperature (ºC)	Relative Humidity (%)	Temperature (ºC)	Relative Humidity (%)
1-Aug-09	27	98	29	85
2-Aug-09	27	87	29	85
3-Aug-09	27	89	29	84
4-Aug-09	27	90	29	89
5-Aug-09	27	94.5	29	88
6-Aug-09	27	94.5	29	83.5
7-Aug-09	26	91	29	81
8-Aug-09	28	90	30	88
9-Aug-09	27	91	31	73
10-Aug-09	28	86	32	73
11-Aug-09	29	82	30	81.5
12-Aug-09	27	88	30	79
13-Aug-09	27	94	29	85
14-Aug-09	26	92	30	87
15-Aug-09	26	94	29	83
16-Aug-09	27	93	28	81
17-Aug-09	27	94	29	83

18-Aug-09	26	91	28	85
19-Aug-09	26	94	30	80
20-Aug-09	27	90	31	77
21-Aug-09	26	94.5	30	79
22-Aug-09	27	91	31	84
23-Aug-09	27	89	30	76
24-Aug-09	26	93	30	71
25-Aug-09	27	93	28	85
26-Aug-09	27	88	31	75
27-Aug-09	30	76	31	78
28-Aug-09	28	91	31	74
29-Aug-09	27	91	30	88
30-Aug-09	26	90	29	84
31-Aug-09	28	89	30	81
Mean	27.03	90.60	29.71	81.48

Date	September-09			
	Morning		Afternoon	
	Temperature (ºC)	Relative Humidity (%)	Temperature (ºC)	Relative Humidity (%)
1-Sep-09	27	92	29	85
2-Sep-09	28	89	30	78
3-Sep-09	25	90	30	71
4-Sep-09	26	78	32	84
5-Sep-09	27	84	29	82
6-Sep-09	26	90	29	86
7-Sep-09	28	85	31	77
8-Sep-09	28	87	31	77
9-Sep-09	27	91	30	76
10-Sep-09	29	85	32	72
11-Sep-09	27	87	30	78
12-Sep-09	27	84	30	72
13-Sep-09	26	82	31	76
14-Sep-09	28	86.5	31	75
15-Sep-09	27	95.5	30	81
16-Sep-09	27	89	29	81

17-Sep-09	26	90	31	76
18-Sep-09	28	91	30	75
19-Sep-09	27	92	31	84
20-Sep-09	27	90	30	86
21-Sep-09	27	89	32	70
22-Sep-09	28	86.5	34	69
23-Sep-09	27	90	34	71
24-Sep-09	29	85	34	70
25-Sep-09	29	85	35	67
26-Sep-09	27	85.5	33	79
27-Sep-09	25	89	34	78
28-Sep-09	26	90	33	78
29-Sep-09	27	96	36	65
30-Sep-09	29	91	33	80
Mean	27.17	88.17	31.47	76.63

Date	October-09			
	Morning		Afternoon	
	Temperature (°C)	Relative Humidity (%)	Temperature (°C)	Relative Humidity (%)
1-Oct-09	28	90	32	70
2-Oct-09	27	85	30	78
3-Oct-09	28	89	34	76
4-Oct-09	26	95	31	77
5-Oct-09	28	90	30	69
6-Oct-09	27	89	32	76
7-Oct-09	28	90	30	78
8-Oct-09	29	84	31	87
9-Oct-09	28	88.5	34	70.5
10-Oct-09	27	89	32	72
11-Oct-09	29	90	32	80
12-Oct-09	24	84.5	33	77
13-Oct-09	29	83.5	35	67.5
14-Oct-09	28	82	34	78

15-Oct-09	29	95	31	78
16-Oct-09	28	90	33	80
17-Oct-09	29	89	32	82
18-Oct-09	28	84.5	30	80
19-Oct-09	27	89	31	77
20-Oct-09	29	90	33	68
21-Oct-09	27	88	30	80
22-Oct-09	29	91	32	78
23-Oct-09	27	95	30	88
24-Oct-09	26	92	30	79
25-Oct-09	26	90.5	31	84
26-Oct-09	28	86.5	31	85
27-Oct-09	28	89	29	70.5
28-Oct-09	29	90	32	78
29-Oct-09	26	89	31	84
30-Oct-09	26	92	30	85
31-Oct-09	28	90	30	84
Mean	27.61	89.03	31.48	77.95

Date	November-09			
	Morning		Afternoon	
	Temperature (^oC)	Relative Humidity (%)	Temperature (^oC)	Relative Humidity (%)
1-Nov-09	26	91	29	80
2-Nov-09	27	89	29	79
3-Nov-09	28	90	31	83
4-Nov-09	27	91	33	85
5-Nov-09	28	85.6	30	79
6-Nov-09	29	90	33	85
7-Nov-09	28	89	30	82
8-Nov-09	26	84	29	82
9-Nov-09	28	88.5	32	84
Mean	27.44	88.68	30.67	82.11

Appendix Plate 1: Hygrometre

Appendix Plate 2: Sodium chloride concentration on groundnut leaves