GYPSUM FERTILIZATION ALLEVIATES THE TOXIC EFFECTS OF NaCl-INDUCED SALT STRESS IN MAIZE

A THESIS

BY

MOST. KHADIZATUL KUBRA

Student No. 1601257

Session: 2021-22

Thesis Semester: July-December, 2022

MASTER OF SCIENCE (M. S.)

IN

AGRONOMY

DEPARTMENT OF AGRONOMY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR

DECEMBER 2022

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DINAJPUR

DECEMBER, 2022

Dedicated

To

My Beloved

Parents and All Well Wishers

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ABSTRACT

A pot experiment was conducted at the Agronomy Shade House, Dept. of Agronomy, Hajee Mohammad Danesh Science & Technology University, Dinajpur from November,2021 to March,2022 to determine the alleviation of salt stress (NaC1 0, 100 and 150 mM) through Gypsum (G: 0, 150, 175 and 200 kg ha^{-1}) in BARI Hybrid Maize 9. The experiment was laid out in Completely Randomized Design (CRD) with three replications. Gypsum alleviate salt stress on growth and metabolic activities of Maize plants. The data which were collected during the experiment are plant height, number of leaves, fresh and dry weight of plant parts (leaf, stem and root), plant water status (RWC, WSD, WRC, WUC) of plant parts ($leaf^{–1}$) and bio-chemical properties (Ca^{2+}, K^+, Na^+) of shoot and root in different days of interval (50,75 and 100 DAS). The results reveal that, NaCl treatment induced drastic reduction in general parameters like growth, plant height (cm), number of leaves per plant and fresh and dry weight of maize leaves(g) , stems (g) and roots (g) whereas gypsum promote that parameters like plant height was highest (102.83 cm) where gypsum was present with salt. It also induced drastic reduction in physiological parameters (RWC and WRC), and increase of WSD (35.26%) and WUC (8.02%) due to the application of gypsum. Salinity also increase chemical components like Na^+ and reduce Ca^{2+} and K^+ in maize but promote Ca^{2+} (492.13 & 419.46 mg/100g and K^+ (946.77 & 921.28 mg/100 g) where applied gypsum in both shoot and root. In the majority of cases with the application of 175 kg ha^{-1} of gypsum caused partial decrease in the deleterious effects of salinity in all parameters of this study. From this experiment, it was found that under control and stressed condition 175 kg ha^{-1} of gypsum gave the best result for all the growth, physiological and biochemical parameters.

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LIST OF ABBREVIATIONS

AEZ	:	Agro Ecological Zone
BADC	:	Bangladesh Agricultural Development Corporation
BARI	:	Bangladesh Agricultural Research Institute
BBS	:	Bangladesh Bureau of Statistics
CRD	:	Completely Randomized Design
CV	:	Co-efficient Of Variance
DAS	:	Days After Sowing
df	:	Degrees of Freedom
DMRT	:	Duncan’s Multiple Range Test
DW	:	Dry Weight
EC	:	Electrical Conductivity
et al.	:	And other
FAO	:	Food and Agriculture Organization
FW	:	Fresh Weight
HSTU	:	Hajee Mohammad Danesh Science and Technology University
g	:	gram(s)
G	:	Gypsum
IWM	:	Institute of Water Modeling
LAI	:	Leaf Area Index
LSD	:	least Significant Difference
PH	:	Plant Height
QPM	:	Quality Protein Maize
RWC	:	Relative Water Content

ROS	:	Reactive Oxyzen Spices
S	:	Salt
SRDI	:	Soil Resources and Development Institute
UNDP	:	United Nations Development Program
WSD	:	Water Saturation Deficit
WRC	:	Water Retention Capacity
WUC	:	Water Uptake Capacity

CHAPTER 1

INTRODUCTION

Salt stress is one of the most important leading causes of abiotic stress on plants in arid and semi-arid regions, and markedly decreases the normal growth and development of important crops. Environmental pressures have a negative impact on a plant's development and productivity, especially if the plant is salinity sensitive (Islam *et al*., 2011). Due to climate change, Bangladesh is regarded as one of the most susceptible nations in the world. Tides and salinity from the Bay of Bengal define the Ganges delta's coastline region in Bangladesh. The main issue facing the nation's coastal region is salinity intrusion brought on by a decrease in fresh water flow from upstream, salinization of groundwater, and variations in soil salinity. The increased saline levels have negative effects on aquaculture, domestic and industrial water use, as well as in agriculture especially in case of irrigation. As a result of the external drivers of change, the current temporal and geographical fluctuation in salinity is anticipated to get worse (IWM, 2014). Bangladesh, a deltaic plain, has very low topography and is very flat, with the exception of the northeast and south-east. One-third of the country is subject to tidal excursions, and 10% of it is just 1 m above mean sea level. The Bay of Bengal is parallel to its 710 km long coastline. Over 30% of Bangladesh's net cultivable land is located in the Bay of Bengal's coastal region, where salt conditions influence over 53% of that land (Haque, 2006). In addition, more land in that region is anticipated to turn salty in the near future as a result of the sea level rise brought on by the greenhouse effect. Another issue is that as more and more land is being irrigated globally, more and more places are becoming sensitive to the effects of salinity stress. Additionally, places near the ocean are more susceptible to salinity, particularly those where tidal water is present. When tide water is lost and the soil is left dry, the issue becomes acute. The population of Bangladesh is growing quickly from 75 million in 1971 to 169.3 million in 2021, while agriculture output is declining due to the detrimental effects of different environmental pressures (BBS, 2021). Salinization-related soil deterioration is one of the pressures that everyone is concerned about. Following the cropping cycle of

Fallow-Aman-Fallow, a sizable portion of cultivable land in coastal areas remains fallow. Utilizing those salt-affected areas might be accomplished by introducing salt-tolerant crops like maize genotypes into the current cropping plan. To address the looming issue of food security in our nation, it is crucial to create salinity-tolerant cultivars and ameliorative mechanisms.

Maize (*Zea mays* L.) is one of the most significant cereal crops in the world. The area of maize cultivation is 1186 acres of land where production of maize in the world is now 4116 metric tons (BBS, 2021). It is a dominant crop in many temperate locations today, and is thought to have originated in subtropical areas, most likely in the highlands of Mexico (Miedema, 1982). One of the important crops, it provides food and oil for human use, as well as feed for animals and raw materials for industry (Khatoon *et al*., 2010; Ullah *et al*., 2010). It is farmed in a variety of soil types and climates, and is the third most significant cereal crop after rice and wheat. It belongs to the Poaceae family, and is a significant C_4 plant. It is somewhat sensitive to salt stress (Chinnusamy *et al*., 2005). Nevertheless, maize has a significant intraspecific genetic variation for salt resistance (Mansour *et al*., 2005). Because of its larger range of environmental adaptability, it is a crop that can be grown round the year round, and is more photosynthetically effective than C_3 plants of rice and wheat. Because of its low osmotic potential in the root zone, maize is typically thought of as a species that is very sensitive to salt (Maas and Hoffman, 1977). Root water intake is significantly reduced as soil salt concentration rises due to a decrease in soil osmotic potential. Plant roots may not only be unable to absorb water, but under conditions of acute salt stress, they may also lose their water to the soil, according to McKersie and Leshem (1994). To feed the millions of hungry people in Bangladesh, quality protein maize (QPM) has long been a goal. Given that maize has more digestible protein than other cereals and that many individuals are protein malnourished, it should be prioritized (Ahamed, 2010). Furthermore, as maize is a key component of chicken feed, demand for maize would rise dramatically due to Bangladesh's expanding poultry sector.

Salinity in the soil is a significant issue for agriculture worldwide because it has an impact on practically all aspects of plant function. Worldwide, millions of hectares of land are too saline to support profitable agricultural production, and additional land is becoming unproductive every year as a result of salt buildup. According to current estimates, almost one billion acres of land are damaged by salt (Chen, 2023). Salinity is thought to harm 20% of the 300 million acres of irrigated cropland worldwide. Four nations, namely China, India, Pakistan, and the United States, account for more than half of all irrigated agricultural fields that have been damaged by salt (FAO and ITPS, 2015). As a result of low precipitation, excessive evaporation, and irrigation with saltwater, soil salinity is rising (Teimouri *et al*., 2009). High concentrations of ions, particularly NaCl, in the soil or irrigation water pose the biggest challenges to the economic crop production in arid climates (Moeinrad, 2008). So, one of the main environmental variables limiting plant growth and productivity, particularly in irrigated fields of arid and semi-arid countries, is salinity (Schleiff, 2008). Because of high evaporator water losses that are greater than precipitation in warm, and dry climates, salt concentration is rising to the upper soil layers (Ebert *et al*., 2002).

For plants, salinity induces abiotic stress conditions such ionic and osmotic stress that result in oxidative damage, reactive oxygen species (ROS) generation, metabolic toxicity, and membrane degradation (Szalai and Janda, 2009). The creation of techniques to increase plants' tolerance and resistance to salt stress is crucial. According to Ouda *et al*. (2008), maize is relatively susceptible to salt (Carpici *et al*., 2009). Ion accumulation causes leaf destruction and the gradual demise of the plant in sensitive cultivars, which store ions more quickly than tolerant cultivars (Munns, 2002). High salinity results in both ionic and hyper osmotic stress, which alters plant metabolism and produces changes in water potentials, ionic imbalances, and particular ion toxicity (Tester and Devenport, 2003). Salinity alters the metabolisms of plants in addition to their morphology, and the extent of alteration varies on the cultivars, the length of the stress, and its intensity. Most crops can withstand salinity up to a certain point, after which the yield declines as the salinity rises (Khan *et al*., 2006).

To maximize plant growth and productivity in saline environments, many tactics are used. Creating crop genotypes that are salt tolerant is one of them. Conventional plant breeding techniques take a long time, are tedious, and rely on genetic variety that already exists. Therefore, exogenous application of nutrients source like gypsum that reduce salinity effect in plants to an acceptable level could be a different strategy for dealing with salinity. By encouraging soil aggregation and improving soil physical qualities, gypsum is well known to offer a wide range of advantages as a soil amendment or conditioner. Gypsum can improve water quality by reducing phosphorus (P) losses from soils, reduce soil dispersion, prevent soil crust formation, improve seedling germination, facilitate better water infiltration and soil aeration, improve crop water relations, increase soil drainage, reduce soil erosion and runoff, and improve crop water relations (Amezketa *et al*., 2005; King *et al*., 2016; Kost *et al*., 2014). Gypsum can consequently improve soil's physical and chemical characteristics to give plants better settings for growth. In turn, this might make it easier for plant roots to penetrate deeper into the soil profile and into larger volumes of soil, improving water and nutrient usage efficiency, and thus lowering nutrient input requirements (Dick et al., 2006; Watts and Dick, 2014). The adverse effects of salt stress on several other crops have been previously reviewed, but no updated and comprehensive studies are available on the alleviating of salt stress through gypsum application on maize crop. Therefore, the present study was undertaken with the following objectives:

i) To evaluate gypsum performance to overcome salt stress on maize ,

ii) To find out the optimum dose of gypsum for the cultivation of maize.

CHAPTER II

REVIEW OF LITERATURE

Salinity is one of the major abiotic stresses that adversely affects crop yield. Maize is quite sensitive to salinity and shows reduction in the over growth, yield contributing parameters and photosynthetic potential. The tolerance to salt stress is a complex process that involves morphological physiological and biochemical modifications. Gypsum as a soil amendment or conditioner is important for modulating plant responses to environmental stresses. The available literature on effect of salt stress and ameliorative effects of gypsum on growth, physiological, biochemical changes and yield in plants growing under saline conditions has been reviewed as under:

2.1 Effect of salinity on morphological characteristics

In a study published in 2014, Sozharajan and Natarajan examined the impact of NaCl on the germination and seedling development of *Zea mays* (L.). Seeds of *Zea mays* were planted in glass Petridishes that measured 100 x 15 mm in diameter and were lined with blotting paper. Each petridish was filled with 10 seeds. Petridishes were irrigated with NaCl solutions with concentrations of 25, 50, 75, 100, 125, 150, 175 and 200 mM. A control received ten milliliters of distilled water to moisten it. The growth parameters, water uptake percentage, seed germination rate, and seed water absorption rate were all measured. The collected results demonstrated that rising NaCl concentrations were found to lower the seedlings' germination percentage, germination rate, water intake, growth, and biomass accumulation. At the maximum stress level, both plumule and radical dramatically dropped. Due to ion toxicity, decreased osmotic potential, and oxidative stress, the salt stress reduced seed germination, biomass, and growth of maize seedlings.

Hoque *et al*. (2014) conducted research to determine the germination response of three different NaCl salt levels for the genotypes of maize (*Zea mays* L.) (0 mm, 100 mM and 200 mM). Following a randomized complete block design, seeds were planted and grew on Petri plates on filter paper with three replications of the salt solution stated above as the treatment. As the concentration of NaCl was raised, germination percentage (GP), germination speed (GS), germination index (GI), seedling dry weight (SDW), seed vigor index (SVI), and salt tolerance index (STI) all reduced. As the NaCl levels rose, so did the mean germination time (MGT) and percent reduction in dry weight over control. Different degrees of variations were seen in the interactions between genotypes and salt levels. Conclusion: Genotypes varied in their responses to saline stress during seed germination. Inbred line CZ-7 expressed as the tolerant genotype among the examined genotypes, whereas B73 seemed to be more sensitive during the germination stage.

Akbari *et al*. (2015) studied about influence of salt stress on some characteristics of corn varieties at Islamic Azad University, Zahedan Branch, Zahedan, Iran. Here treatments included salt stress (NaCl: 1, 2.3, 3.6, 4.9 gm/lit), and they found that salinity is one of the serious environmental problems that cause osmotic stress and reduction in plant growth and productivity in irrigated areas of arid and semiarid regions.

Giaveno *et al*. (2007) investigated the morphological and physiological features might be used to select maize genotypes under salt stress in Brazil. The trials were conducted during the germination and early stages of seedling development. During salt stress and stress recovery, measurements of root and shoot weight, leaf area, root and leaf water potential, photochemical efficiency, and growth rate were made. Their findings showed that germination is genetically variable, but that there is no correlation between germination and early seedling growth under salt stress. In breeding programs, characteristics related to seedling vigor, such as seedling weight and growth rate and photochemical efficiency under stress, can be employed as selection criteria to identify salt-tolerant maize.

The effect of salinity levels on maize was studied by some researchers reported that salt stress (NaCl) caused decreases in germination, shoot and root lengths and fresh mass in maize.

Salinity reduces plant growth, alters ionic relation by ionic and osmotic effects and induces oxidative stress in plants (Parida and Das, 2005; Molassiotis *et al*., 2006; Silva *et al*., 2008).

Rajpur *et al*. (2006) investigated how wheat variety Inqlab performed in a pot experiment with addition of various NaCl concentrations of 2, 4, 6, 8 and 10 EC (dSm^{-1}) and discovered that increasing soil salinity gradually reduced plant height.

A pot experiment was created by Memon *et al*. (2007) at Sindh Agriculture University in Tando Jam, Pakistan, using silty clay toam soil in *Sorghum bicolor* L. Sarokartuho variety. The crop was continually watered with fresh (control) and salinized (EC of 2, 3, and 5 dSm^{-1}) waters. Plant height and fodder yield (fresh and dry weight) per plant dropped over time as the salt of the water increased.

Studies revealed that an increase in salinity not only inhibited germination but also delayed the start of germination (Hussain *et al*., 2013; Rahman *et al*., 2008). This adds to the research by Akbarimoghaddam *et al*. (2011) that found that in bread wheat varieties, germination is delayed and reduced when the concentration of NaCl is increased.

Wheat productivity is negatively impacted by salt stress, which is linked to a decrease in germination, development, changed reproductive behavior and enzymatic activity, interrupted photosynthesis, hormonal imbalance, oxidative stress, and yield losses, according to a review by Seleiman *et al*. (2022). Therefore, a deeper comprehension of how wheat (plants) respond to salinity stress is crucial for developing mitigation and countermeasures to deal with salt stress. To deal with salt stress tolerance, a variety of methods can be utilized, such as the selection of suitable cultivars, traditional breeding, and molecular techniques. But these methods are time-consuming, expensive, and labor-intensive. Management techniques continue to be useful for enhancing wheat performance under salinity stress. To enhance wheat performance under salinity stress, it is vital to use arbuscular mycorrhizal fungi, plant growth-promoting rhizobacteria, exogenous phytohormone administration, seed priming, and nutrition control.

Tantawy *et al*. (2009) investigated how salinity affected plant height. Due to the toxicity of Na and Cl, poorer plant height and a decrease in stem fresh weight in salt conditions may be associated. Another factor that may contribute to growth loss is disorder in the translocation and distribution of minerals, particularly K and Ca^{2+} .In the case of lentils, the results demonstrated that plant height, leaf count, and leaf area gradually reduced as salt levels increased (4 to 6 dSm^{-1}), as also noted by Islam *et al*. (2006).

Behdani *et al*. (2008) also discovered that Medicago and Trifolium sp. cultivated in saline circumstances saw a decrease in plant height and leaf width. Both the plant's vegetative and reproductive development are impacted. Salinity frequently slows root growth more than it does shoot growth (Lauchli and Epstein, 1990). According to Karlidag *et al*. (2009), strawberry plants growing in salty environments saw a drop in root and shoot fresh and dry weights. Similar outcomes were seen in strawberry by Pirlak and Esitken (2004) and in cucumber by Kaya *et al*. (2002).

In an investigation on the morphological response of rape (*Brassica campestris* L.) in saline environments was conducted by Dabnath *et al*. (2003), and noticed that high salt decreased agricultural yield and yield qualities as well as plant height, primary and secondary branches, and leaf count. More morphological traits are susceptible to saline stress.

Numerous physiological processes, including seed germination and plant development, can be impacted by salt stress. Because many agricultural fields naturally contain high amounts of NaCl, salinity is one of the most important environmental issues on the planet (Parida and Das, 2005). It reduces crop productivity and alters plant metabolism, resulting in a decreased water potential, ion imbalance, and toxicity. Severe salt stress may occasionally even endanger life.

Crop performance may be adversely affected by salinity as a result of nutritional disorders. These disorders may derive from the effect on nutrient availability, competitive uptake, transport or partitioning within the plant (Silva *et al*., 2008).

Northwest A&F University, Yangling, Shaanxi, China served as the subject of an experiment conducted by Ahanger *et al*. (2019). They discovered that exposure to salt (100 mM NaCl) stress had a negative impact on the production of carotenoid and chlorophyll as well as the effectiveness of photosynthetic reactions. Increases in photosynthetic rate, stomatal conductance, and internal CO_2 concentration were all brought about by N supplementation, with the effects being more pronounced in seedlings given greater N doses. Protease and lipoxygenase activity significantly decreased under non-saline circumstances at both N levels, resulting in lessened oxidative damage. These results were accompanied by a decrease in the production of harmful radicals including hydrogen peroxide and superoxide as well as lipid peroxidation in seedlings that had received a N supplement. They proposed that N availability controlled salinity tolerance by inhibiting Na absorption and enhancing the main mechanisms of tolerance.

2.2 Effect of salinity on physiological and biochemical characteristics

Salinity has a twofold impact on plant growth through specific ion toxicities and an osmotic effect on plant water uptake. Water availability decreased due to soil salinity, and cellular ionic equilibrium was altered by ionic stress and osmotic stress (Kirst, 1989). High salt concentrations have an impact on a plant’s physiology at both the cellular and systemic levels (Murphy and Durako, 2003). By negatively influencing a number of physiological and biochemical processes, such as photosynthesis, antioxidant capability, and ion homeostasis in maize genotypes, salt stress inhibited plant development (Ashraf, 2004).

Çiçek and Çakirlar (2002) conducted an experiment in University of Hacettepe, Faculty of Science, Department of Biology regarding salinity and stress impacts on the growth and development of two maize cultivars grown in Turkey's Southeastern Anatolia Region (SAR) were examined. Stress brought on by salinity had an impact on both plants' shoot length, overall fresh and dry weight, and leaf area.

Muhammad *et al*. (2010) created a quick and easy mass screening method for choosing maize hybrids with the best salt tolerance at the wire house, Stress Physiology Laboratory of NIAB in Faisalabad, Pakistan,. Using the solution-culture method, the genetic variation for salt tolerance in hybrid maize was evaluated. The study was carried out in solution cultures exposed to four salinity levels (control, 40, 80, and 120 mM NaCl). Maize seedlings that were seven days old were transplanted in iron tubs with half-strength Hoagland nutritional solutions, and salinized with table salt (NaCl). Ten hybrids of maize were tested against four salt levels, and each hybrid seedlings growth in saline circumstances was compared as a share of the control values. At various salinity levels, significant changes were seen in the root, shoot, and biomass lengths of several hybrids. The hybrid Pioneer32B33 and Pioneer30Y87 has a high biomass, root shoot fresh weight, and high K^+/Na^+ ratio, and it demonstrated the best salt tolerance performance at all salinity levels on a general basis, according to the analysis of a leaf sample for inorganic osmolytes (sodium, potassium, and calcium).

In order to obtain insight into tolerance mechanisms, certain morphological and biochemical responses of maize to salinity and drought in open field in Tunisia were studied by Romdhane *et al*. (2020). Optimal water supply (control, 100% of maximum evapotranspiration-ETM), irrigation at 70% ETM (moderate drought) and at 35% ETM (severe drought), and optimal supply of water containing 3 g NaCl L^{-1} (moderate salinity) and 6 g NaCl L^{-1} (severe salinity) were the five treatments used until the seedlings reached maturity. Here, they show that severe drought and salinity both significantly reduced leaf area and above-ground biomass at the silking stage (74% and 55%, respectively), showing that the photosynthetic leaf apparatus is highly sensitive and that drought has a greater impact than salinity. The grain yield losses were also exacerbated under extreme stress conditions, such as severe drought (85% versus controls) and severe salinity (73%). It is possible to use the leaf area and its relative water content as markers for efficient screening of maize genotypes for greater stress tolerance maize to drought and salinity in open field in Tunisia with the goal of increasing grain output.

Mahboob *et al*. (2017) carried out a glass house experiment at the Nuclear Institute of Agriculture, Tando Jam, Pakistan, to examine the potential of various wheat genotypes for physiological features critical to their salt tolerance. Ten wheat genotypes were tested under two salinity levels, together with a salt-tolerant control (LU-26s) (control and 120 mM NaCl). Wheat genotypes' physiological properties, as well as growth and yield characteristics, were strongly impacted by salt stress. However, in terms of plant height, productive tiller, plant biomass, and grain production per plant, LU-26s, CT-09117, NRL-1237, NRL-1235, Tatara, and NIA-AS-14-2 outperformed these cultivars. These genotypes also showed the least amount of chlorophyll degradation and a notable increase in the levels of proline, glycine betaine (GB), total phenols (TP), and total soluble sugars (TSS) in the plant's internal composition. They also kept their high potassium (K^+) content by limiting their uptake of sodium (Na^+) in response to salt stress. The NIA-AS-9 and 4 genotypes performed mediocrely under saline stress, whereas the NIA-AS-14-8 and CT-09149 genotypes failed to adapt osmotically, leading to poor growth and yield. While K+, proline, and TSS were all positively connected with wheat grain production, Na^+ concentrations under salinity were negatively correlated with it. Wheat genotypes CT-09117, NRL-1237, NRL 1235, NIA-AS-14-2, and Tatara could be characterized as salt resistant and may be further examined for mechanisms conferring salinity tolerance. These metrics related to growth and yield, physiological characteristics, and ion buildup.

The effect of salt on chlorophylls may be inhibited by the inhibition of particular enzymes necessary for the production of green pigments. Increased chlorophyllase activity could be the cause of the drop in chlorophyll. Salt stress may cause a decrease in chlorophyll content because it affects the stability of membranes (Bidel *et al*., 2007). Similar findings were obtained for the lentil plant and cucurbit species total leaf concentration (Tester and Davenport, 2003; Taffouo *et al*., 2008).

In a pot experiment with three salinity levels (0.6, 0.9, and 10.9 dS/m) in sesame, Ali and Islam (2005) found that the weight of the stem and leaves dropped as the salinity increased. According to Ahmed and Rasul (2005), salinity-induced drops in leaf dry weight were observed in green gram crop.

The most notable aspect of rice cultivated under salt stress circumstances is the increase in proline concentration (Roy *et al*., 1992). Proline accumulated substantially more in the leaves of blackgram cultivars under high salinity compared to the control treatment, and it accumulated even more in salt-sensitive types than salt-tolerant ones (Ashraf, 1989; Kaur, 2009). Chickpea and soybean were both shown to have similar elevated proline levels when exposed to salt stress (Soussi *et al*., 1999). (Mannan *et al*., 2009).

In response to salt stress, leaf relative water content decreased while electrolyte leakage increased in strawberry (Karlidag *et al*., 2009). According to Parida and Das (2005), as salinity rises, the relative water content, water potential, and osmotic potential of plants all decrease. In an experiment on mungbean with varying salinities, Amira and Qados (2010) found that salinity stress led to a considerable rise in Na, Cl, Ca, and Mg contents while considerably lowering N, P, and K contents.

Due to the sensitivity of the majority of crop plants to salinity, which is brought on by high salt concentrations in the soil, salinity is one of the harshest environmental variables restricting crop plant productivity. Reduced growth rate is one of the earliest impacts of salt stress on plants. First, the presence of salt in the soil lowers the plant's ability to absorb water, which quickly slows down growth. This initial phase of the growth response results from the osmotic action of the salty soil solution and has a number of consequences like those of water stress (Munns, 2002; Nahar and Hasanuzzaman, 2009).

High salt concentrations in the soil solution, high concentrations of potentially toxic ions, and nutrient imbalance due to decreased mineral uptake, internal distribution, and transport are the three main issues that plants grown in saline soils must deal with (Greenway and Munns, 1980; Marschner, 1995). Plant growth is slowed by salinity, which also affects ionic relationships through ionic and osmotic effects and causes oxidative stress (Parida and Das, 2005; Molassiotis *et al*., 2006; Silva *et al*., 2008).

Salinity alters the way that plants use water, slows their pace of growth, and changes how their metabolic processes operate (Munns, 1993).

The decrease in pigment levels may be caused by the ions' (Na and Cl) inhibitory influence on the biosynthesis of the various pigment fractions and their breakdown, or by the effect of NaCl on chloroplast structure (Natr and Lawlor, 2005). One of the physiological processes that has the most potential for promoting crop growth and yield is photosynthesis. As a result, crop plants' ultimate biological yield or commercial yield can be raised by either increasing the rate of photosynthesis or through other methods (Niu *et al*., 1995).

2.3 Effect of salinity on yield and yield contributing characteristics

Widespread reductions in crop yields worldwide are being brought on by high salt content in soil (Sekmen *et al*., 2007). Hoque *et al*. (2015) conducted a study to assess the salt tolerance of nine maize genotypes using solution-culture and vermiculite-culture techniques. Under 0 mm, 100 mM, and 200 mM NaCl salt stress, ten seedling characteristics (shoot length, root length, leaf number, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, Na^+ content, K^+ content, and K^+/Na^+ ratio) were measured. The results showed that, in comparison to the control, fresh root and shoot weight under saline conditions showed a significant growth loss.

Leila *et al*. (2016) conducted an experiment on a field trial in Tunisia. The effects of drought and salinity on maize phenology, shoot and root characteristics, and productivity were examined after the following treatments that is two sub-optimal irrigation levels (70% and 35% ETM), with standard water quality; two levels of water salinity (3 and 6 g NaCl L^{-1}) at 100% ETM, compared with optimal water supply (100% ETM, control) and standard quality. Irrigation at 70% ETM turned out to be a sustainable practice, with limited changes in phenology but with a fall in yield of 22%. Extreme drought impaired root weight, whereas salinity did not affect this root trait. Salinity and drought significantly alter phenology, causing both silking and physiological maturity to occur much sooner.

The most severe drought is the extreme condition, which causes an anticipation of 10 and 12 days, respectively, but with impaired yield (-84% vs. controls) .They concluded that scheduling silking time under mild water or salinity stress enables more effective water management during the delicate growth phases of maize.

Alam (2013) conducted a pot experiment at the net house of the Department of Soil Science, BAU, Mymensingh, Bangladesh during November 2011 to April 2012 to study the impact of salinity and the reduction of soil salinity in maize with foliar application of proline. As plant materials, BARI Hybrid Maize-5 and Hybrid Maize Pacific-987 types of maize were employed. There were nine (9) different treatment combinations, including control, 25 mM, 50 mM, 25 mM + 25 mM proline, 50 mM + 25 mM proline, 25 mM + 50 mM, 25 mM + 50 mM + 50 mM proline, 25 mM + 100 mM proline, and 50 mM + 100 mM proline. The findings showed that salt stress significantly decreased the quantity of grains in each column of both kinds of maize and BARI Hybrid Maize-5 plants exposed to saline caused a considerable drop in cob length.

To determine the effects of salt stress on 11 varieties of bread wheat, Kandil *et al*. (2012) conducted a laboratory experiment at the Giza Central Seed Testing Laboratory of the Central Administration for Seed Testing and Certification, Ministry of Agriculture, Egypt. The 11 varieties were Sakha 93, Gemmeza 7, Egaseed 7, Sakha 94, Gemmeza 10, Egaseed 3, Masr 2, Masr 1, Gemmeza 9, Sids 1, and Giza 168. According to the research, the shoot and root lengths of wheat varieties decreased as saline levels rose.

Datta *et al*. (2009) evaluated the effects of salt stress on five cultivars of wheat, including HOW-234, HD-2689, RAJ-4101, RAJ-4123, and HD-2045, at varied salinity levels (0, 25, 50, 75, 100, 125, and 150 mM NaCl). Data showed that with increasing subsequent treatment, the fresh weight and dry weight of both roots and shoots of all kinds were dramatically reduced.

In the wire-house of the Department of Soil Science, Sindh Agriculture University, Pakistan, a pot experiment was carried out by Kalhoro *et al*. (2016) to investigate the impact of salts stress on the growth and yield of wheat (cv. Inqalab). With various salts ($MgCl_2$ + $CaCl_2$ + Na_2SO_4), the soil was artificially salinized to a range of salinity values, including EC 2.16, 4.0, 6.0, 8.0, and 10.0 dSm^{-1}. The experiment's salinized soil had a sandy clay texture, an alkaline response (pH > 7.0), and a moderate amount of organic matter (0.95%). The findings demonstrated that when salinity increased, the ECe, Na^+, Ca^{2+}, Mg^{2+}, and CI values of the soil increased while the K^+, sodium absorption ratio (SAR), and exchangeable sodium percentage (ESP) values decreased. Plant height, spike length, number of spikelets, 1000-grain weight, and yield all reduced with increasing salinity (straw and grain).

Turki *et al*. (2012) studied 55 types and accessions of common and durum wheat to ascertain the effects of salt on grain production, protein content, and thousand kernel weight (TKW) (16 winter wheat varieties and 39 spring wheat accessions). The findings demonstrated that 45 common and durum wheat cultivars had lower grain yields following salt treatment (100 mM of NaCl solution).

In seven wheat genotypes (Lu-26s, Sarsabz, Bhittai, KTDH22, Khirman, B-7012 and Bakhtawar) grown under two salinity levels (NaCl 1.5 and 12 dSm^{-1}) in the cemented tanks containing river sand, Khan *et al*. (2010) investigated the effect of NaCl stress on yield and various physiological parameters (leaf area, osmotic potential, After one week of germination under normal conditions, salt treatments were applied to the seeds. Salinity was created by irrigating the crop with 1/4th Hoagland fertilizer solution at the appropriate NaCl concentrations every two weeks or as needed. Salinity, they discovered, decreased grain output.

Hassan (2010) conducted an experiment on an Egyptian wheat cultivar cv. Giza 63 that was subjected to salinity levels (0 and 50 mM NaCl). The results revealed a significant decrease in yield characteristics, particularly in the number of ears per plant and 1000-grain mass.

In an experiment, Khan (2007) found that high salt levels (10 dSm^{-1}) had a detrimental influence on the maximum plant heights, shoot fresh and dry weights, and other metrics. Due to the exposure of plants to different salt levels, yield and yield components of different genotypes were drastically decreased.

In a pot experiment, Akram *et al*. (2002) investigated the impact of salinity (10, 15, and 20 dSm^{-1}) on wheat types that were salt tolerant (234/2), medium responsive (243/1), and susceptible (Fsd 83) in terms of yield and yield components. According to their findings, salinity decreased the yield per plant for all kinds, but the vulnerable variety was the most negatively impacted.

2.4 Alleviation of salt stress through gypsum

Yamica *et al*. (2021) conducted an experiment in Sidomukti Village District, Brondong Lamongan. The research used split-plot designs with main plots were varieties (P-21 and Bisma) and subplots were ameliorant types (without ameliorant, cow manure, gypsum, Sunhemp (*Crotalaria juncea*) and rice straw). Applying ameliorants to salty soil can reduce stress from salinity affects maize growth and yield. Both the maize cultivars P-21 and Bisma responded favorably to gypsum and cow manure for boosting growth and output. In addition to lowering the levels of proline, Na, and Cl shoot root ratio, gypsum and cow were also raising the nitrogen, phosphorus, and potassium content of plants. It demonstrated that gypsum and cow manure were effective in increasing the growth and yield of both maize varieties P-21 and Bisma under saline conditions.

Akhtar *et al*. (2013) conducted an experiment at the Plant Physiology and Biochemistry Laboratory, Department of Botany, Jahangirnagar, Bangladesh. They looked at how salt stress affected the water relations of two wheat cultivars (Akbar and Kanchan). The two wheat cultivars were raised in pots with salinities of 0 and 150 mM NaCl. Gypsum was used to apply calcium in amounts of 0.12, 0.24, and 0.36g pot^{-1}, or 20, 40, and 60 kg ha^{-1}, respectively. Salinity increased WSD and WUC while decreasing RWC, WRC, exudation rate, and leaf. The plant hydration status in both cultivars was enhanced by the application of higher Ca concentrations. According to the findings, increased Ca^{2+} enhances the plant hydration status and boosts salt tolerance.

Murtaza *et al*. (2017) conducted an experiment at Department of Environmental Sciences, COMSATS Institute of Information Technology, Vehari, Pakistan to determine crop yield and N use efficiency (NUE) from a saline-sodic soil with and without application of gypsum. Here treatments included two N application rates (15% and 30%) higher than the recommended one to the normal soil, and gypsum added at 50% and 100% of soil gypsum requirement (SGR) to the saline–sodic soil, both cultivated with rice and wheat during 2011-2013. When gypsum was added at 50% of SGR, the effect was the most noticeable. In comparison to regular soil, crop production and NUE in saline-sodic soils remained considerably lower ($P < 0.05$). Gypsum treatment, however, resulted in a reduction of this differential from 47% to 17% as both yield and NUE rose significantly. Wheat continued to have a greater crop yield and NUE than rice. Higher N doses with gypsum treatment at 50% SGR showed most beneficial during the first year, but suggested N together with gypsum at 50% SGR became more profitable in the second year. All of these findings persuade that applying gypsum can improve saline-sodic soil, consequently enhancing agricultural production and NUE.

Bello (2012) investigated an experiment that took place in early 2008 on the main campus of Mekelle University in the Tigray region of Ethiopia. The same amount of water was used to irrigate pots containing wheat seedlings that had varying degrees of gypsum content (0, 50, 100, and 150 kg/pot). The initial results of the soil investigation indicate that the soil is salty, and its salinity is confirmed by its heavy clay structure and high EC value. Results indicated that applying gypsum considerably improved all metrics evaluated. The results showed that using 100 kg per pot responded better early on and 50 kg per pot boosted yield and growth afterwards. Utilizing 50kg/pot improved crop performance across all characters with the least amount of variation from the control. The use of gypsum on saline soils is a superior alternative for increasing productivity on alkaline soils, according to the considerable effect on germination percentage, root-dry weight, fresh weight, days to heading of plants, and plant height. An earlier reaction of 100 kg/pot and a later response of 50 kg/pot show that the salinity effect diminishes over time.

Through irrigation application and gypsum additions, Mamun *et al*. (2019) conducted a field experiment at Shamnagar, Satkhira Sadar, Bangladesh to increase wheat yield in salty environments. L-880-43 and BARIghom 26 were two wheat cultivars that were utilized as test crops. There were six different treatments, including the control (no irrigation), one irrigation at the vegetative stage with canal water (canal water is rainwater harvested in natural or man-made canals), one irrigation at the vegetative stage with STW water + gypsum application @ 200 Kg/ha, one irrigation at the vegetative stage with saline canal water + gypsum application @ 200 Kg/ha, and one irrigation at the vegetative stage with irrigation at the heading and flowering stages with canal water. The findings demonstrated that both wheat cultivars growth and yield components were significantly reduced by soil salt. Both cultivars development and yield components under the soil salinity were greatly boosted by irrigation application and gypsum supplements. Both cultivars' grain yields were likewise decreased by soil salinity. In saline circumstances, irrigation water applied in combination with gypsum additions produced higher yields than irrigation water applied alone. Gypsum is utilized as an amendment because it lowers the salinity of the soil.

In a moderately salt-affected soil with ECe: 4.71 dS m^{-1}, pHs: 9.18 and SAR: 31.82, a two-year study was undertaken by Ahmed *et al*. (2021) to evaluate the effects of foliar application of salicylic acid and L-tryptophan with and without gypsum on wheat crop. Details of the treatments are as follows: (A). Amendments 1: 50% GR gypsum, 2: no gypsum (B). T1: Control, T2: SA @10-5 M, T3: L-TRP @10-5 M, and T4: SA + L-TRP (each @10-5 M in 1:1). The results showed that T4 (SA + L-TRP @ 10-5 M in a 1:1 ratio with gypsum application @ 50% of GR) had higher growth and yield metrics. Finally they found the combination of SA and L-tryptophan hormones with gypsum can be used positively to increase the commercial benefit of wheat crops in salt-affected soil conditions and also stated that the hormones L-tryptophan and SA perform synergistically, and the use of these hormones with gypsum can be applied positively to enhance the commercial profit of rice crops in salt-affected soil.

At the Soil Salinity Research Institute (SSRI), Pindi Bhattian, Pakistan, Saqib *et al*. (2020) conducted an experiment to determine the ameliorative effects of humic acid (HA) and gypsum on rice and wheat crops grown in saline-sodic conditions (ECe = 4.71 dS m^{-1}, SAR = 31.82, pHs = 9.10). Treatments T1 was a control, T2 was gypsum at 100% GR, T3 was gypsum at 75% GR + HA @ 15 kg ha-1, T4 was gypsum at 75% GR + HA @ 30 kg ha-1, T5 was gypsum at 50% GR + HA @ 15 kg ha-1, and T6 was gypsum at 50% GR + HA @ 30 kg ha^{-1}. The combined use of HA and gypsum greatly improved the qualities of the saline-sodic field and significantly elevated growth and yield parameters. When gypsum + humic acid were used at 75% GR + HA @ 30 kg ha^{-1}, followed by gypsum @ 100% GR, the maximum plant height, 1000-grain weight, paddy yield, and grain yield of rice and wheat crops were achieved. In both treatments, the soil chemical properties (pHs, ECe, and SAR) were below the safe limits. The pH (6.70), ECe (27.60 dS/m), SAR (54.96%), hydraulic conductivity (9.75%), and bulk density (3.94%) were all decreased relative to their initial values by gypsum at 75% GR and humic acid at 30 kg ha^{-1}. Therefore, it was determined that gypsum at 75% GR combined with humic acid at 30 Kg ha^{-1} was just as efficient as gypsum at 100% GR for increasing wheat and rice crop yields and regaining the degraded qualities of salt-affected soils.

In order to determine how rice would respond to foliar applications of the phytohormones salicylic acid (SA @ 10-5 M) and L-tryptophan (L-TRP @ 10-5 M) alone or in combination with soil-applied gypsum (with and without gypsum) under saline-sodic soil for the two years that followed, Ahmed *et al*. (2021) conducted an experiment at the Soil Salinity Research Institute Pindi Bhat (2014-2015). The combined treatment of phytohormones (salicylic acid + L-tryptophan @ 10-5 M in a 1:1 ratio) with 50% gypsum requirement of soil, according to the results, significantly ($P < 0.05$) influenced rice plant growth and yield attributes and increased the grain yield by up to 26% and 32.80% in 2014 and 2015, respectively, compared to control. The results also showed that separate applications of salicylic acid or L-tryptophan improved the behavior of rice plants under salinity stress when compared to controls, but the combined treatment of SA+L-TRP produced the best outcomes in terms of yield and growth characteristics. Gypsum @ 50% GR produced higher ameliorative efficiency in terms of improved ECe, SAR, pHs, BD, and HC compared to no application of gypsum. Results showed that the combined effects of phytohormones increased the salinity tolerance of rice plants, indicating that the synergistic interactions between SA and L-tryptophan are effective at reducing salt stress.

Andrade *et al*. (2018) stated that the highest levels of elemental sulfur applied (1.39 and 1.99 t ha^{-1}) promoted the best growth of sorghum and the saline irrigation level equivalent to 60% of the field capacity and the sulfur level of 1.39 t ha^{-1} was sufficient to reduce soil pH and salinity to a level that best promoted sorghum growth.

Bello *et al*. (2021) examined data from Saudi Arabia, Nigeria, and Egypt and discovered that salinity, which is caused by an excessive buildup of salt (NaCl), hinders soil and crop productivity in more than 900 million ha of arable lands worldwide; to improve the productivity of saline soils, gypsum ($CaSO_4.2H_2O$) as well as bio-organic amendments (combined use of organic materials, such as compost, and in order to increase the Ca^{2+}/Na^+ ratio in the soil solution, $CaSO_4.2H_2O$ controls the exchange of sodium (Na^+) for calcium (Ca^{2+}) on the clay surfaces. Ca^{2+} also encourages a greater K^+/Na^+ ratio intracellularly. Phytohormones, amino acids, glutathione, and osmoprotectants essential triggers in plants' responses to salinity stress as well as phytohormones, amino acids, and glutathione are simultaneously produced in greater quantities by gypsum, which provides crops with sulfur (S) for improved growth and yield. Overall, growing glycophytes and halophytes with integrated applications of gypsum and bio-organic amendments is a highly promising method for increasing the productivity of saline soils.

A pot experiment has been carried out by Shatil *et al*. (2021) to determine the ameliorative effect of gypsum on the yield of sugar beet (*Beta vulgaris*) grown under various levels of salt stress, a pot experiment was carried out in the net house of the Department of Agronomy, Bangladesh Agricultural University, Mymensingh. Two factors were used in the experiment: three levels of gypsum (0, 1 and 2 g gypsum kg^{-1} soil) and five levels of salinity (0, 25, 50, 75, and 100 mM NaCl) in a Randomized Complete Block Design with three replications. Gypsum and salinity levels interacted significantly to affect plant height, leaf weight, leaf length, and beet production. With 1g of gypsum per kilogram of soil, the highest plant height (68.30 cm) and beet output (20.50 t ha^{-1}) were achieved. In the control area, which lacked salinity and gypsum application, the highest leaf weight (22.14 t ha^{-1}) was discovered. The longest leaf (41.30 cm) was produced with 2 g of gypsum per kilogram of soil under no-salinity conditions. With NaCl 100 mM and no gypsum application, the lowest plant height (42.57 cm), leaf weight (9.48 t ha^{-1}), leaf length (27.90 cm), and beet yield (4.56 t ha^{-1}) were attained. The result showed that the parameters like plant weight, plant height, leaf weight, beet length ,beet girth and beet yield decreased with increasing salinity levels but gypsum had a significant effect on those parameters.

In a pot experiment, Rahman *et al*. (2016) investigated an laboratory experiment on Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur and studied how gypsum fertilizer may reduce the salinity of various mungbean genotypes. For screening test eleven mungbean genotype (BARI Mung-2, BARI Mung-3, BARI Mung-4, BARI Mung-5, BARI Mung-6, BINA moog 1, BINA moog 2, BINA moog 5, BINA moog 6, BINA moog 7 and BINA moog 8) were tested in three salinity levels (0, 50 and 100 mM) of NaCl. The seedling growth characteristics of all mungbean genotypes were reduced with increasing level of salinity compared to control. BINA moog 8 was also used for alleviation of salinity through gypsum ($CaSO_4.2H_2O$) application at five different treatments (Control, 50 mM NaCl, 100 mM NaCl, 50 mM NaCl +10 mM gypsum and 100 mM NaCl + 10 mM gypsum). Most of the morphological characters viz., length of shoot and root, branches plant^{-1} , weight of leaf, stem, root, yield and yield contributing characters (pods plant^{-1}, seeds plant^{-1}, 1000 seed weight) performed better at 50 mM NaCl with 10 mM gypsum level, and showed lower performance in respect of above terms at 100 mM saline condition. According to their findings, BINA moog 8 should be grown on saline soil by applying 10 Mm gypsum at three growth stages (pre-flowering, flowering and pod formation stage).

According to a study by Cao *et al*. (2019) at Agricultural Research Center of Ningxia University in Ningxia, China. They measured the effects of flue gas desulfurization (FGD) gypsum, straw compost (SC), the SC mixed with FGD gypsum on site and the SC co-composted with FGD gypsum on soil properties, root nutrient uptake, shoot growth, crop yields and tomato quality under continuous saline water irrigation. The treatments considered were (i) untreated soils irrigated with non-saline water (control), (ii) untreated soils irrigated with saline water (SW), (iii) soils treated with SC and irrigated with saline water (SW + C), (iv) soils treated with FGD gypsum and irrigated with saline water (SW + G), (v) soils treated with the SC mixed with FGD gypsum on site and irrigated with saline water (SW + C + G), and (vi) soils treated with co-composted FGD gypsum-SC and irrigated with saline water (SW + GC). Finally they found that the use of co-composted FGD gypsum -SC led to the maximum fruit yield and the least amount of blossom-end rot when saline water irrigation was used continuously.

An open field experiment was carried out by Ashour and Mahmoud (2017) during 2015 and 2016 seasons at the experimental nursery of the Ornamental Horticulture Department, Faculty of Agriculture, Cairo University, Egypt to investigate the effects of foliar application of nano silicon with different concentrations and gypsum soil application on growth, flowering and chemical constituents of Jatropha integerrima plants irrigated with different levels of saline water (1000, 2000, and 4000 ppm). They found that foliar application of nano silicon and soil addition of gypsum treatments enhanced vegetative parameters and chemical constituents.

CHAPTER III

MATERIALS AND METHODS

A pot experiment was carried out to ascertain the gypsum level for maximum growth and yield of maize under different levels of saline water at different stage. This chapter deals with the materials and methods that were used in the experiment. It includes short description of location of the experimental plot, characteristic of soil, climate, materials of the experiment, raising of seedlings, treatments, layout and design, land preparation, manuring and fertilizing, transplanting. Intercultural operations, harvesting, collection of data and statistical analysis which are given below:

3.1 Location and duration

The pot experiment conducted at the Agronomy shade house, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during the period of July 2021 to June, 2022. Geographically, the experiment site is located at 25°38 N Latitude and 88°41'E longitude at an elevation of 37.5 m above the mean sea level. The land of the experimental site was a medium high land belonging the Agroecological zone 1 (AEZ-1) named Old Himalayan Peidmont Plain (UNDP and FAO, 1988).

3.2 Soil properties

The soil was collected from 0-15 cm depth from agronomy Research Field, Department of Agronomy, HSTU, Dinajpur, The soil was sandy loam in texture having pH 5.52. The electrical conductivity (EC) 2.0 dSm^{-1} and medium in organic matter. Morphological, physiological and chemical characteristics of the soil have been presented in Appendix I.

3.3 Weather and climate

The experimental site is suited in the sub-tropical climate zone and characterized by heavy rainfall during the months of July to October and medium to low during the rest of the year. The crop was grown in summer season when the day length (sunshine period) was 14-16 hours per day. Temperature during the cropping period ranged between 26 and 30 °C with generally 60-95% humidity in the air. The monthly average temperature, humidity, rainfall and sunshine hours prevailed at the experimental site during the cropping season are presented in (Appendix-II).

3.4 Experimental materials

3.4.1 Plant material: The variety of maize used in the experiment was BARI Hybrid Maize 9. The duration of this crop is 100-110 days, seed yield is 10-12 t/ha. It can be sown both Kharif-1 and Kharif-2 and also late *Rabi* season throughout the country. The seeds were collected from Bangladesh Agricultural Development Corporation (BADC). The seeds were healthy, vigorous, well matured and free from other crop seeds and inert materials.

3.4.2 Gypsum: Gypsum is a soft sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4 \cdot 2H_2O$. It is widely mined and is used as a fertilizer and as the main constituent in many forms of plaster, blackboard or sidewalk chalk, and drywall.

3.5 Preparation of soil and filling of pots

A total of 36 plastic pots (24 cm x 24 cm) were prepared with 10 kg air dried soil. Collected soil was dried under the sun and removed plant parts, inert materials, visible insects and pests from soil by sieving. Before filling the pot with soil a small brick piece was placed at the bottom hole of the pot. The pots were placed in the shade house.

3.6 Experimental treatments and design

Three levels of saline irrigation water and four levels of gypsum were used in this experiment. The experiment was set up in a factorial completely randomized design with three replications.

The experiment consisted of two factors as follows:- Factor A: It included different concentration of salt solution which are mentioned below:

i) 0 mM NaCl = Control (No salt application), ii) 100 mM NaCl = Application of NaCl in tap water to make 10 dSm^{-1} concentration, and iii) 150 mM NaC1 = Application of NaCl in tap water to make 15 dSm^{-1} concentration mentioned as S_0, S_1 and S_2, respectively. Factor B: It consisted of four levels of Gypsum which are mentioned below:

i) 0 ppm of G - No application of G, ii) 150 ppm of G = Application of G, @ 150 mg/L water, iii) 175 ppm of G - Application of G @ 175 mg/L water, iv) 200 ppm of G Application of G @ 200 mg/L water and designated as G_0, G_1, G_2 and G_3, respectively.

Total 12 treatment combinations were as follows: i) S_0G_0, ii) S_0G_1, iii) S_0G_2, iv) S_0G_3, V)S_1G_0, vi) S_1G_1, vii) S_1G_2, viii) S_1G_3, ix) S_2G_0, x) S_2G_1, xi) S_2G_2 and xii) S_2G_3. The experiment was set up in a two factor completely randomized design (CRD) with three replications. Thus 36 experimental pots were placed in ambient air at the shade house premises of Agronomy Department of HSTU, Dinajpur.

3.7 Application of fertilizers in the pot

The required amount of fertilizers was estimated at the rate of 350, 250, 175, 12 and 8 kg/ha of urea, TSP, MoP, zinc sulphate and boric acid, respectively. As per recommendation for the area of each pot (.0576 sq. m), the required urea, TSP, MoP, zinc sulphate and boric acid were applied @ 2.016 g, 1.44g, 1.008 g, 0.058g and 0.046g/pot, respectively. All fertilizers were applied as basal application. Gypsum was applied as per treatment in each pot.

3.8 Sowing of seeds

The seeds of maize (BARI Hybrid Maize 9) were sown on the 20 November, 2021 by hand in pot to raise the seedling. After filling the pot, 20 seeds were sown in each pot. After sowing seeds pots were arranged and applied water as per treatments.

3.9 Imposition of salinity treatments

As per the treatment the required amount of NaCl was applied in the pot during application of water. The pods were irrigated with gradually increasing saline water of 25, 50, 75 mM NaCl in all saline treated pots, then increased to 150 mM NaCl to severe saline treated pots for hardening of seedlings. Saline water was applied as per treatment specification up to harvesting.

3.10 Intercultural operations

Proper intercultural operations were done for better growth and development of maize plants in pots.

3.10.1 Weeding and mulching

Weeding and mulching were accomplished as and when necessary to keep the crop free from weeds, better soil aeration and to break the soil crust. At pre-flowering stage the intensity of weeds was increased, and hand weeding was done as when necessary to keep the pots free from weeds.

3.10.2 Thinning

Seeds started germination from twelve days after sowing (DAS). Thinning was done in each pot gradually by keeping six healthy seedlings as to maintain optimum plant population in each pot.

3.10.3 Irrigation

Irrigation was done as per requirements with saline water based on treatment.

3.10.4. Insect and disease control

There was incidence of insects so Ripcord was used to control the insect. There was no disease incidence during the period of experiment, so no disease control measure was adopted in the experiment.

3.11 Harvesting

The crop was harvested during the period from 13 April to 20 March, 2022 when there were no cobs as it was an experiment of measuring morphological, growth, physiological and biochemical characters.

3.12 Parameters assessed

3.12.1 Measurement of morphological characteristics

3.12.1.1 Plant height (cm): The height of plant was recorded in centimeter (cm) at 50, 75, 100 DAS and at harvest. After thinning there were six plants in each pot. Data were recorded from 2 plants from each pot plant height was recorded as per treatment. The height was measured from the ground level to the tip of the plant by a meter scale.

3.12.1.2 Number of leaves: The number of leaves plant was counted at 50, 75, 100 DAS and at harvest. Data were recorded from 2 planst from each pot and number of leaves plant^{-1} was recorded as per treatment.

3.12.1.3 Leaf area index: Leaf area index (LAI) was calculated as the ratio of leaf area to land area as suggested by Watson (1952).

3.12.2 Measurement of physiological parameters

3.12.2.1 Relative leaf water content

The leaves of maize plants from each treatment were taken carefully. Fresh weight of fully expanded third trifoliate leaves was taken. The plants were kept immersed in distilled water for 24 hours at room temperature. The turgid weights of those leaves were measured. Afterwards all the materials were oven dried at 80 °C for 72 hours in order to take dry weight. The fresh, turgid and dry weights of leaf segments were used to calculate relative water content (Barr and Weatherley, 1962), water saturation deficit (Saneoka *et al*., 1995), water retention capacity (Islam, 2001), and water uptake capacity (Hasan *et al*., 2019). The formula of all the parameters was presented below:

3.12.2.2.1 $\text{Relative leaf water content (RWC)} = \dfrac{\text{Fresh weight - Dry weight}}{\text{Turgid weight - Dry weight}} \times 100$

3.12.2.2.2 Water saturation deficit (WSD) = 100 - RWC

3.12.2.2.3 $\text{Water retention capacity (WRC)} = \dfrac{\text{Turgid weight}}{\text{Dry weight}}$

3.12.2.2.4 $\text{Water Uptake Capacity (WUC)} = \dfrac{\text{Turgid weight - Fresh weight}}{\text{Dry weight}}$

3.12.3 Measurement of yield contributing characteristics

3.12.3.1 Fresh weight & dry weights (leaf, stem, root): Seedlings from each plastic pot were collected as a sampling. Then the leaf, shoot & root fresh weights were calculated for each treatment combination. After calculating the fresh weight, samples were kept in an oven, and then the leaf, shoot and root were dried at 80°C for 72 hours. The dry weights were calculated for each treatment combination.

3.13 Estimation of Na^+, K^+ and Ca^{2+}

1. Estimation of Calcium (Ca) from plant extract by Complexometric Method of Titration Using Na_2-EDTA as a Complexing Agent

Apparatus required

1. Burette with stand, 2. Pipette, 3. Conical flask or Erlenmeyer flask, 4. Volumetric flask, 5. Measuring cylinder, 6. Beaker with watch glass, 7. Electrical balance. and 8. Glass rod, etc.

Chemicals required

1. Disodium EDTA 2. Sodium Hydroxide (NaOH 10%) 3. Calcon Indicator 4.Methanol.

5. Masking agent: a) Hydroxylamine hydrogen chloride b) Potassium ferocyanide c) Triethanolamine (TEA)

Preparation of Different Reagents or Chemicals

2. Preparation of Na_2-EDTA solution (0.02 M)

Exactly 7.44 g of disodium salt of EDTA (Na_2- EDTA) was dissolved in a liter volumetric flask containing about 400 ml distilled water. The flask was shaken thoroughly until Na_2EDTA completely dissolved. The volume was up to the mark with distilled water. This solution gives 0.02 M Na_2-EDTA solution.

3. Preparation of calcon indicator solution

400 mg calcon indicator powder of AR grade was taken in a 100 ml volumetric flask containing about 30 ml methanol or ethanol. The flask was shaken thoroughly and the volume was up to the mark with methanol or ethanol.

4. Preparation of NaOH Solution (10%)

50 g NaOH AR grade was dissolved in a 500 ml volumetric flask containing approximately 200 ml distilled water. The flask was shaken thoroughly to mix NaOH with water and the volume was up to the mark with distilled water.

Procedure

(1) 5 ml of plant extract solution was taken in a 250 ml conical flask.

(2) 20 ml distilled water was added into the conical flask and shaken thoroughly.

(3) 10 drops of each masking agent of a) Hydroxylamine hydrogen chloride, b) Potassium ferocyanide c) Triethanolamine(TEA) was added .

(4) 5 ml NaOH buffer solution was added and shaken thoroughly.

(5) Calcon indicator of 5-6 drops was added into the conical flask (depending on the concentration of the indicator solution) and shaken the flask thoroughly.

(6) Then titration was done against 0.01 M Na_2-EDTA solution from burette.

(7) The titration was continued until pink color of the solution completely turns to pure blue color.

(8) The procedure was repeated at least 3 times.

(9) A blank procedure was conducted also by taking all the reagents as above except calcium stock solution.5 ml more distilled water was taken into conical flask instead of calcium solution.

(10 The data was tabulated and calculated the amount of calcium present in the prepared solution.

Formula of Calculation:

1 ml 1M EDTA ≡ 1ml 1M Ca = 40.08 mg Ca

2. Estimation of Potassium from plant extract/Water Soluble Muriate of Potash with the Help of a Flame Emission Spectrophotometer.

Apparatus required

1. Flame emission spectrophotometer or Flame photometer, 2.Volumetric flasks, 3. Beakers, 4. Pipettes, 5. Glass rod, 6. Electric heater/Hot plate with magnetic stirrer, 7. Electrical balance, 8. Filter paper (Whatman No.1), and 9. Oven.

Chemicals required

1. Muriate of potash (MP), KCI- Fertilizer grade, 2. Potassium chloride (KCl), AR grade, and 3. Distilled water.

Preparation of different reagents

a) Preparation of primary standard of potassium solutions (1000 ppm K)

Previously dried 1.907g KCl (AR grade) was taken in a liter volumetric flask. About 300-400 ml of distilled water was added and shaken it thoroughly until it is dissolved. The volume was made up to the mark with distilled water. The concentration of this solution is 1000 ppm K .

b) Preparation of secondary standard potassium solution (100 ppm K)

25 ml of 1000 ppm K solution was taken in a 250 ml volumetric flask. The volume was made up to the mark with distilled water and shaken it thoroughly. Thus, 100 ppm K solution is prepared.

c) Preparation of standard series solutions of potassium (5, 10, 15, 20, 25, 30, 40, 50 and 60 ppm K)

Prepared a series of potassium standard solutions containing 5, 10, 15, 20, 25, 30, 40, 50 and 60 ppm K by pipeting 5, 10,15, 20, 25, 30, 40, 50 and 60 ml of 100 ppm K solution in 9 (nine) different 100 ml volumetric flasks, respectively. Made the volume up to the mark with distilled water in each flask and shaked the flasks thoroughly. Thus, a series of potassium standard solution are prepared.

**** NB : Estimation of Potassium and Sodium procedure same. Only Standard series solution is different**

3.14 Statistical analysis:

The data were compiled and subjected to statistical analysis with the help of a computer-based statistical program using the Statistix 10. The mean separation test was done with the Duncan’s Multiple Range Test (DMRT) test at p = 0.05.

CHAPTER IV

RESULTS AND DISCUSSION

The present investigation was carried out to study the improvement of maize productivity through gypsum fertilization under saline condition. Various observations on morphological and physiological changes were recorded at different growth stages. Salinity induced comparative changes in growth and yield contributing characters of maize are discussed in this chapter. The results have been presented and discussed in the different tables and possible interpretations given under the following headings:

4.1 Effect of gypsum on the morphological traits of maize under saline environment

4.1.1 Plant height

The plant height varied significantly due to imposition of different concentrations of saline stress at different days after sowing (DAS). Data revealed that the salt stress reduced the plant height of maize at all sampling dates (ANOVA Table 1). At 50, 75 and 100 DAS the tallest plant (59.38, 78.68 and 84.65 cm respectively) was found from S_0 (0 mM of NaCl i.e., control), and the shortest plant (32.87, 43.99 and 45.87 cm respectively) was observed from S_2 (150 mM of NaCl). Salinity significantly reduced the plant height of maize varieties. On the other hand, at 50, 75 and 100 DAS the tallest plant (58.18, 79.32 and 82.97 cm respectively) was found from G_2 (175 kg ha^{-1} of gypsum), and the shortest plant (36.36, 51.68 and 51.97 cm respectively) was observed from G_0 (0 kg $ha^{-1}$of gypsum) under salt-stressed plants. Bhatti *et al.* (2004) reported that increasing salinity levels drastically decreased the plant height. The result are in agreement with the findings of Ismail (2003), Rajpar and Sial (2002), Ashraf *et al.* (2002), who reported that plant height was decreased in the stress treatments which might be due to the fact that cell division or cell enlargement was inhibited under salinity stress Application of gypsum enhanced the plant height remarkably at 50, 75 and 100 DAS. The tallest plant (71.60, 97.67 and 102.83 cm respectively) was recorded from S_0G_2 (0 mM NaCl + 175 kg ha^{-1} gypsum), while the shortest plant (21.83, 31.43 and 31.23 cm respectively) was recorded from S_2G_0 (150 mM NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 1). Under low and high salt condition 175 kg ha^{-1} of gypsum gave the best result in the terms of plant height.

Table 1. Effects of gypsum on the plant height under saline environment at different DAS

Treatments	Plant height (cm)		
	50 DAS	75 DAS	100 DAS
	Salinity level (mM)		
0	59.38 a	78.68 a	84.65 a
100	45.48 b	65.89 b	71.65 b
150	32.87 c	43.99 c	45.87 c
CV (%)	6.41	2.80	3.36
	Gypsum levels (kg ha^{-1})		
0	36.36 c	51.68 c	51.97 d
150	43.17 b	52.17 c	65.34 c
175	58.18 a	79.32 a	82.97 a
200	45.92 b	68.24 b	69.28 b
CV (%)	6.41	2.80	3.36
	Interaction of salinity X gypsum levels		
S_0G_0	55.90 cd	60.13 de	68.83 d
S_0G_1	61.83 bc	74.00 c	89.70 b
S_0G_2	71.60 a	97.67 a	102.83 a
S_0G_3	48.17 de	82.90 b	77.23 c
S_1G_0	31.33 g	63.47 d	55.83 fg
S_1G_1	37.33 fg	45.00 f	65.17 de
S_1G_2	65.80 ab	82.43 b	86.50 b
S_1G_3	47.43 de	72.67 c	79.10 c
S_2G_0	21.83 h	31.43 h	31.23 i
S_2G_1	30.33 gh	37.50 g	41.17 h
S_2G_2	37.13 fg	57.87 e	59.57 ef
S_2G_3	42.17 ef	49.17 f	51.50 g
CV(%	6.41	2.80	3.36

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

4.1.2 Number of leaves

Number of leaves plant^{-1} of maize measured at 50, 75 and 100 DAS showed significant variation for different levels of salinity. However, the highest number of leaves plant^{-1} of 6.33, 7.00 and 9.33, was found from S_0 (0 mM of NaCl i.e., control), and the lowest number of leaves plant^{-1} of 4.75, 5.58 and 6.58) was observed from S_2 (150 mM of NaCl) at 50, 75 and 100 DAS respectively.

The number of leaves plant^{-1} varied significantly at different DAS due to application of different doses of gypsum both in saline and non-saline condition (ANOVA Table 2). Application of gypsum alleviated the adverse effects of salt stress and increased the number of leaves plant^{-1}. At 50, 75 and 100 DAS the highest number of leaves plant^{-1} (7.67, 8.44 and 8.44 respectively) was found from G_2 (175 kg ha^{-1} of gypsum), whereas the number of leaves plant^{-1} (3.44, 4.22 and 5.78 respectively) was observed from G_0 (0 kg ha^{-1} of gypsum).

Table 2. Effect of gypsum on the number of leaves under saline environment at different DAS

Treatments	Number of leaves		
	50 DAS	75 DAS	100 DAS
Salinity level (mM)			
0	6.33 a	7.00 a	9.33 a
100	5.67 b	6.42 b	7.75 b
150	4.75 c	5.58 c	6.58 c
CV (%)	11.13	7.27	11.23
Gypsum levels (kg ha^{-1})			
0	3.44 d	4.22 d	5.78 c
150	5.00 c	5.67 c	7.44 b
175	7.67 a	8.44 a	8.44 a
200	6.22 b	7.00 b	8.56 b
CV (%)	11.13	7.27	11.23
Interaction of salinity X gypsum levels			
S_0G_0	3.67 ef	4.33 e	7.00 cd
S_0G_1	6.00 bcd	6.00 cd	9.00 abc
S_0G_2	8.67 a	9.67 a	11.33 a
S_0G_3	7.00 abc	8.00 b	10.00 ab
S_1G_0	3.67 ef	4.33 e	6.33 de
S_1G_1	5.00 de	6.00 cd	7.00 cd
S_1G_2	7.67 ab	8.33 ab	9.33 abc
S_1G_3	6.33 bcd	7.00 bc	8.33 bcd
S_2G_0	3.00 f	4.00 e	4.00 e
S_2G_1	4.00 ef	5.00 de	6.33 de
S_2G_2	6.67 bcd	7.33 bc	8.67 bcd
S_2G_3	5.33 cde	6.00 cd	7.33 cd
CV (%)	11.13	7.27	11.23

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

Statistically significant variation was recorded in terms of number of leaves plant^{-1} at 50, 75 and 100 DAS due to interaction effect of gypsum and levels of salinity. Nonetheless, the highest number of leaves plant^{-1} (8.67, 9.67 and 11.33 respectively) was recorded from S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while lowest number of leaves plant^{-1} (3.00, 4.00 and 4.00 respectively) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 2). Salt stress reduced the number of leaves, and the extent of reduction was different days under saline stresses. The gradual decrease in the number of leaves per plant might be due to decrease nutrient availability caused by the increased salinity. This result confirms the findings of Hussain *et al.* (2007), Asgari *et al.* (2012), Paul (2014), and Akter (2014).

4.2 Effect of gypsum on the growth traits of maize under saline environment

4.2.1. Fresh weight of different plant parts

4.2.1.1 Total leaves

Fresh weight of total leaves of maize at 50, 75 and 100 DAS showed significant variation for different levels of salinity (ANOVA Table 3). The highest fresh weight of total leaves (8.84, 11.59 and 13.65 g) was found from S_0 (0 mM of NaCl i.e., control), and the lowest fresh weight of total leaves (2.07, 3.03 and 4.35 g,) was observed from S_2 (150 mM of NaCl of NaCl) at 50, 75 and 100 DAS respectively. Similar results were also reported by several authors such as Memon *et al.* (2007) and Aziz (2003) for mungbean. Fresh weight of total leaves varied significantly at different DAS due to application of different doses of gypsum. At 50, 75 and 100 DAS the highest fresh weight of total leaves (6.63, 9.01 and 10.31 g respectively) was found from G_2 (175 kg ha^{-1} of gypsum), and the lowest fresh weight of total leaves (3.03, 4.41 and 6.74 g respectively) was observed from G_0 (0 kg ha^{-1} of gypsum). Statistically significant variation was recorded in terms of fresh weight of total leaves at 50, 75 and 100 DAS due to interaction effect of gypsum and levels of salinity. However, the highest fresh weight of total leaves (11.55, 14.19 and 16.15 g respectively) was recorded from S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while the lowest fresh weight of total leaves (1.47, 1.67 and 3.66 g respectively) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 3)

Table 3. Effects of gypsum on the fresh weight of leaves of maize under saline environment

Treatments	Total leaves FW (g)		
	50 DAS	75 DAS	100 DAS
Salinity level (mM)			
0	8.84 a	11.59 a	13.65 a
100	3.82 b	5.76 b	7.92 b
150	2.07 c	3.03 c	4.35 c
CV (%)	2.49	4.49	2.46
Gypsum levels (kg ha^{-1})			
0	3.03 d	4.41 d	6.74 d
150	4.43 c	5.97 c	8.51 c
175	6.63 a	9.01 a	10.31 a
200	5.55 b	7.77 b	8.99 b
CV (%)	2.49	4.49	2.46
Interaction of salinity X gypsum levels			
S_0G_0	5.97 d	9.09 d	11.08 d
S_0G_1	7.79 c	10.67 c	12.68 c
S_0G_2	11.55 a	14.19 a	16.15 a
S_0G_3	10.05 b	12.39 b	14.70 b
S_1G_0	1.63 h	2.48 gh	5.49 h
S_1G_1	3.75 f	4.52 f	8.80 f
S_1G_2	5.70 d	8.37 de	9.71 e
S_1G_3	4.19 e	7.67 e	7.67 g
S_2G_0	1.47 h	1.67 h	3.66 k
S_2G_1	1.75 h	2.72 g	4.04 jk
S_2G_2	2.64 g	4.48 f	5.08 hi
S_2G_3	2.41 g	3.26 g	4.62 ij
CV (%)	2.49	4.49	2.46

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

4.2.1.2 Stems

Due to increase in salinity, fresh weight of stem decreased significantly in maize (ANOVA Table 3). The highest fresh weight of stem (9.16, 18.78 and 24.99 g) was found from S_0 (0 mM of NaCl i.e., control), and the lowest fresh weight of stem (2.78, 6.06 and 9.09 g,) was observed from S_2 (150 mM of NaCl) at 50, 75 and 100 DAS respectively. This result agreed with the result of the study conducted by El-Kafafi *et al*. (2015) in Mungbean. On the other hand, at 50, 75 and 100 DAS the highest fresh weight of stem (8.29, 14.99 and 21.05 g respectively) was found from G_2 (175 kg ha^{-1} of gypsum), and the lowest fresh weight of stem (3.27, 8.30 and 9.73 g respectively) was observed from G_0 (0 kg ha^{-1}

of gypsum). Statistically significant variation was recorded in terms of fresh weight of stem at 50, 75 and 100 DAS due to interaction effect of gypsum and levels of salinity.

Table 4. Effects of gypsum on the stems of maize under saline environment

Treatments	Stem FW (g)		
	50 DAS	75 DAS	100 DAS
	Salinity level (mM)		
0	9.16 a	18.78 a	24.99 a
100	4.59 b	8.30 b	11.60 b
150	2.78 c	6.06 c	9.09 c
CV (%)	8.05	14.46	3.41
	Gypsum levels (kg ha^{-1})		
0	3.27 d	8.30 c	9.73 d
150	4.77 c	10.96 b	15.51 b
175	8.29 a	14.99 a	21.05 a
200	5.71 b	9.93 bc	14.63 c
CV (%)	8.05	14.46	3.41
	Interaction of salinity X gypsum levels		
S_0G_0	5.65 d	15.28 b	17.42 d
S_0G_1	8.20 bc	19.23 b	22.26 c
S_0G_2	13.67 a	25.69 a	33.39 a
S_0G_3	9.13 b	14.91 bc	26.92 b
S_1G_0	2.36 g	5.65 def	7.09 g
S_1G_1	3.74 f	8.77 de	13.36 e
S_1G_2	7.16 c	10.23 cd	16.14 d
S_1G_3	5.09 de	8.57 def	9.81 f
S_2G_0	1.81 g	3.97 f	4.68 h
S_2G_1	2.36 g	4.87 ef	10.93 f
S_2G_2	4.05 ef	9.07 de	13.61 e
S_2G_3	2.89 fg	6.32 def	7.16 g
CV (%)	8.05	14.46	3.41

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

At 50, 75 and 100 DAS, the highest fresh weight of stem (13.67, 25.69 and 33.40 g respectively) was recorded from S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while lowest fresh weight of stem (1.81, 3.97 and 4.68 g respectively) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 4). The reduction of stem diameter caused by salt stress is achieved by the reduction of growth (plant height and dry matter). This result is in agreement with the findings of Levent *et al*. (2007), who showed that salinization stress entails a reduction in stem diameter. Similar results were observed by Javaid *et al*. (2002), Hussain *et al.* (2007), and Gurbanov and Molazem (2009).

4.2.1.3 Roots

The fresh weight of root decreased significantly in maize with increasing salinity (ANOVA Table 4). The highest fresh weight of root at 50, 75 and 100 DAS was found from S_0 (0 mM of NaCl i.e., control) (2.74, 3.39 and 3.50 g respectively), and the lowest fresh weight of root (0.51, 1.35 and 1.61 g respectively) was observed from S_2 (150 mM of NaCl). This result is in agreed with the result of the study conducted by El-Kafafi *et al*. (2015) in Mungbean. In contrast, at 50, 75 and 100 DAS the highest fresh weight of root (2.14, 3.01 and 3.34 g respectively) was found from G_2 (175 kg ha^{-1} of gypsum), and the lowest fresh weight of root (0.62, 0.93 and 1.05 g respectively) was observed from G_0 (0 kg ha^{-1} of gypsum).

Statistically significant variation was recorded in terms of fresh weight of root at 50, 75 and 100 DAS due to interaction effect of gypsum and levels of salinity. The highest fresh weight of root (3.86, 4.88 and 4.97 g) was recorded from S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while lowest fresh weight of root (0.20, 0.49 and 0.59 g) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination at 50, 75 and 100 DAS respectively (Table 5).

Table 5. Effects of gypsum on the root fresh weight of maize under saline environment

Treatments	Root FW (g)		
	50 DAS	75 DAS	100 DAS
Salinity level (mM)			
0	2.74 a	3.39 a	3.50 a
100	0.98 b	1.23 c	1.74 b
150	0.51 c	1.35 b	1.61 c
CV (%)	17.93	2.07	1.99
Gypsum levels (kg ha^{-1})			
0	0.62 d	0.93 d	1.05 d
150	1.21 c	1.45 c	2.04 c
175	2.14 a	3.01 a	3.34 a
200	1.68 b	2.57 b	2.71 b
CV (%)	17.93	2.07	1.99
Interaction of salinity X gypsum levels			
S_0G_0	1.32 cd	1.86 f	1.99 e
S_0G_1	2.62 b	2.88 c	2.99 c
S_0G_2	3.86 a	4.88 a	4.97 a
S_0G_3	3.17 ab	3.95 b	4.07 b
S_1G_0	0.34 e	0.45 i	0.58 h
S_1G_1	0.59 de	0.65 h	1.67 f
S_1G_2	1.72 c	1.98 e	2.17 d
S_1G_3	1.27 cd	1.83 f	2.01 e
S_2G_0	0.20 e	0.49 i	0.59 h
S_2G_1	0.41 e	0.81 g	1.45 g
S_2G_2	0.84 de	2.17 d	2.87 c
S_2G_3	0.59 de	1.93 ef	2.04 de
CV(%)	17.93	2.07	1.99

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

The root fresh weight was found significant variation among treatments of all the maize varieties when grown under normal and saline conditions. Due to increase in salinity, the shoot fresh weight decreased significantly for all the maize varieties. Due to increase in salinity, the shoot fresh weight decreased significantly for all the maize varieties (Hassan *et al*., 2018). Similar results were reported by Sarwar and Ashraf (2003) for wheat and Meloni *et al*. (2001) for cotton.

4.2.2 Dry weight of different plant parts

4.2.2.1 Total leaves

The dry weight of total leaves of maize showed significant variation for different levels of salinity, and it decreased gradually with increasing salinity (ANOVA Table 5).

Table 6. Effects of gypsum on the dry weight of leaves of maize under saline environment

Treatments	Total leaves DW (g)		
	50 DAS	75 DAS	100 DAS
	Salinity level (mM)		
0	1.39 a	2.40 a	3.52 a
100	0.48 b	1.47 b	1.96 b
150	0.21 c	0.72 c	0.96 c
CV(%)	3.19	2.62	17.07
	Gypsum levels (kg ha^{-1})		
0	0.39 d	0.89 d	1.46 c
150	0.54 c	1.16 c	1.81 bc
175	0.99 a	2.22 a	3.04 a
200	0.85 b	1.85 b	2.28 b
CV(%)	3.19	2.62	17.07
	Interaction of salinity X gypsum levels		
S_0G_0	0.79 d	1.87 d	2.47 bcd
S_0G_1	1.09 c	2.13 c	3.10 bc
S_0G_2	1.92 a	3.06 a	5.06 a
S_0G_3	1.77 b	2.55 b	3.46 b
S_1G_0	0.27 h	0.46 g	1.44 def
S_1G_1	0.38 g	0.83 f	1.63 de
S_1G_2	0.69 e	2.45 b	2.41 bcd
S_1G_3	0.56 f	2.15 c	2.36 cd
S_2G_0	0.11 j	0.33 h	0.49 f
S_2G_1	0.15 ij	0.52 g	0.71 ef
S_2G_2	0.38 g	1.16 e	1.64 de
S_2G_3	0.22 hi	0.85 f	1.02 ef
CV (%)	3.19	2.62	17.07

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

However, the highest dry weight of total leaves of 1.39, 2.40 and 3.52 g was found from S_0 (0 mM of NaCl i.e., control), and the lowest fresh weight of total leaves of 0.21, 0.72 and 0.96 g) was observed from S_2 (150 mM of NaCl) at 50, 75 and 100 DAS respectively. Similar results were also reported by several authors such as Aziz (2003) and Memon *et al.* (2007) for mungbean, Islam *et al*. (2011) for foxtail millet and proso millet.

The dry weight of total leaves varied significantly at different DAS due to application of different doses of gypsum. At 50, 75 and 100 DAS, the highest dry weight of total leaves (0.99, 2.22 and 3.04 g respectively) was found from G_2 (175 kg ha^{-1} of gypsum), while the lowest fresh weight of total leaves (0.39, 0.89 and 1.46 g respectively) was observed from G_0 (0 kg ha^{-1} of gypsum). Statistically significant variation was recorded in terms of dry weight of total leaves at 50, 75 and 100 DAS due to interaction effect of gypsum and levels of salinity. However, the treatment combination S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum) produced the highest dry weight of total leaves (1.92, 3.06 and 5.06 g) at 50, 70 and 100 DAS respectively) was recorded from, while lowest fresh weight of total leaves (0.11, 0.33 and 0.49 g respectively) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 6). The effect of salinity levels on the total dry leaf weight plant^{-1} of maize was found to be significant in the current study.

4.2.2.2 Stems

The dry weight of stem of maize at 50, 75 and 100 DAS showed significant variation for different levels of salinity (ANOVA Table 5). At 50, 75 and 100 DAS, the highest dry weight of stem (0.93, 1.77 and 2.33 g respectively) was found from S_0 (0 mM of NaCl i.e., control) and the lowest dry weight of stem (0.19, 0.65 and 0.92 g respectively) was observed from S_2 (150 mM of NaCl). The dry weight of stem varied significantly at different DAS due to application of different doses of gypsum. At 50, 75 and 100 DAS the highest fresh weight of stem (0.81, 1.39 and 2.38 g respectively) was found from G_2 (175 kg ha^{-1} of gypsum), and the lowest dry weight of stem (0.27, 0.92 and 0.95 g respectively) was observed from G_0 (0 kg ha^{-1} of gypsum).

The stem dry weight at 50, 75 and 100 DAS significantly was influenced by the interaction effect of gypsum and levels of salinity (Table 7). However, the highest dry weight of stem (1.66, 1.97 and 3.08 g respectively) was recorded from the treatment combination of S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while the lowest fresh weight of stem (0.09, 0.41 and 0.42 g respectively) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum).

Table 7. Effects of gypsum on the dry weight of leaves and stems of maize under saline environment

Treatments	Stem DW(g)		
	50 DAS	75 DAS	100 DAS
Salinity level (mM)			
0	0.93 a	1.77 a	2.33 a
100	0.39 b	1.06 b	1.67 b
150	0.19 c	0.65 c	0.92 c
CV(%)	9.80	3.83	3.16
Gypsum levels (kg ha^{-1})			
0	0.27 d	0.92 d	0.95 d
150	0.36 c	1.09 c	1.36 c
175	0.81 a	1.39 a	2.38 a
200	0.57 b	1.23 b	1.87 b
CV(%)	9.80	3.83	3.16
Interaction of salinity X gypsum levels			
S_0G_0	0.45 cd	1.54 c	1.58 e
S_0G_1	0.56 c	1.76 b	2.11 d
S_0G_2	1.66 a	1.97 a	3.08 a
S_0G_3	1.03 b	1.81 b	2.55 b
S_1G_0	0.28 ef	0.81 gh	0.86 g
S_1G_1	0.36 de	0.95 f	1.36 f
S_1G_2	0.51 c	1.32 d	2.38 c
S_1G_3	0.44 cd	1.18 e	2.08 d
S_2G_0	0.09 g	0.41 j	0.42 i
S_2G_1	0.16 fg	0.57 i	0.60 h
S_2G_2	0.27 ef	0.89 fg	1.67 e
S_2G_3	0.23 efg	0.70 hi	0.97 g
CV(%)	9.80	3.83	3.16

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

Salinity usually affects the plant growth adversely and this adverse effect may be attributed to non-availability of water, disturbance in nutrients causing deficiency and ion toxicity to plant. Extra expenditure of energy for osmotic adjustment or in repair system under salinity causes growth reduction likes stem weight. This result is in line with the result of Hussein *et al.* (2007). The value of stem dry weights of maize cultivars were negatively affected by increasing salt concentration (Carpıcı and Celık *et al*., 2009).

4.2.2.3 Roots

The dry weight of root decreased significantly due to increase in salinity in maize (ANOVA Table 6). However, the highest fresh weight of root (0.61, 1.14 and 1.40 g) was found from S_0 (0 mM of NaCl i.e., control), and the lowest fresh weight of root (0.07, 0.13 and 0.21 g) was observed from S_2 (150 mM of NaCl) at 50, 75 and 100 DAS respectively. On the other hand, the highest fresh weight of root (0.42, 0.85 and 1.09 g) was found from G_2 (175 kg ha^{-1} of gypsum), and the lowest fresh weight of root (0.13, 0.19 and 0.43 g) was observed from G_0 (0 kg ha^{-1} of gypsum) at 50, 75 and 100 DAS respectively.

The interaction effect of gypsum and levels of salinity significantly variation was recorded in terms of dry weight of root at 50, 75 and 100 DAS (Table 8). Nevertheless, the highest dry weight of root (0.89, 1.83 and 1.94 g respectively) was recorded from the treatment combination of S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while lowest fresh weight of root (0.02, 0.07 and 0.11 g respectively) was recorded from the combination of S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) at 50, 75 and 100 DAS respectively.

Reduction in dry weight of plant tissues reflects the increased metabolic energy cost and reduced carbon gain, which are associated with salt adaptation. It also reflects salt impact on tissues, reduction in photosynthesis rates per unit of leaf area (Netondo *et al*., 2004). This result is accordance with the result of Cicek and Cakirlar (2002) in maize cultivars.

Table 8. Effects of gypsum on the root dry weight of maize under saline environment at different DAS

Treatments	Root DW (g)		
	50 DAS	75 DAS	100 DAS
Salinity level (mM)			
0	0.61 a	1.14 a	1.40 a
100	0.15 b	0.34 b	0.61 b
150	0.07 c	0.13 c	0.21 c
CV (%)	11.37	4.17	1.57
Gypsum levels (kg ha^{-1})			
0	0.13 d	0.19 d	0.43 d
150	0.23 c	0.41 c	0.58 c
175	0.42 a	0.85 a	1.09 a
200	0.32 b	0.69 b	0.88 b
CV (%)	11.37	4.17	1.57
Interaction of salinity X gypsum levels			
S_0G_0	0.31 d	0.38 e	0.81 d
S_0G_1	0.54 c	0.72 c	0.97 c
S_0G_2	0.89 a	1.83 a	1.94 a
S_0G_3	0.70 b	1.63 b	1.89 b
S_1G_0	0.06 gh	0.14 gh	0.36 g
S_1G_1	0.12 fg	0.41 e	0.60 e
S_1G_2	0.24 de	0.52 d	0.99 c
S_1G_3	0.17 ef	0.30 f	0.50 f
S_2G_0	0.02 h	0.07 i	0.11 j
S_2G_1	0.04 gh	0.09 hi	0.16 i
S_2G_2	0.12 fg	0.20 g	0.32 g
S_2G_3	0.08 gh	0.14 gh	0.24 h
CV (%)	11.37	4.17	1.57

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

4.2.3 Leaf area, leaf width, leaf length and leaf ratio

4.2.3.1 Leaf area

The effect of salinity level on leaf area index of maize was found significant (ANOVA Table 7). However, the highest leaf area (18120 cm^2) was found from S_0 (0 mM of NaCl i.e., control), and the lowest leaf area (3223 cm^2) was observed from S_2 (150 mM of NaCl). Conversely, the highest leaf area (12173 cm^2) was found from G_2 (175 kg ha^{-1} of gypsum), and the lowest leaf area (6158 cm^2) was observed from G_0 (0 kg ha^{-1} of gypsum). Statistically significant variation was recorded in terms of leaf area due to interaction effect of gypsum and levels of salinity. The highest leaf area (24216 cm^2)

was recorded from S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while lowest leaf area (1580 cm^2) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 9).

4.2.3.2 Leaf width

The highest leaf width (54.36 cm) was found from S_0 (0 mM of NaCl i.e., control), and the lowest leaf width (24.28 cm) was observed from S_2 (150 mM of NaCl). On the other hand, the highest leaf width (47.19 cm) was found from G_2 (175 kg ha^{-1} of gypsum), while the lowest leaf width (27.47 cm) was observed from G_0 (0 kg ha^{-1} of gypsum). Statistically significant variation was recorded in terms of leaf width due to interaction effect of gypsum and levels of salinity (ANOVA Table 7). The highest leaf width (74.69 cm) was recorded from S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), whereas the lowest leaf width (19.09 cm) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 9).

4.2.3.3 Leaf length

Salinity significantly reduced the leaf length of maize plant. However, the highest leaf length (451.45 cm) was recorded from the S_0 treatment (0 mM of NaCl i.e., control), and the lowest leaf length (198.11 cm) was observed from S_2 treatment (150 mM of NaCl). Contrariwise, application of gypsum remarkably attenuated the adverse effects of salt stress and increased the leaf length in this study (ANOVA Table 7). Nonetheless, the highest leaf length (381.10 cm) was found from G_2 (175 kg ha^{-1} of gypsum) and the lowest leaf length (210.11 cm) was observed from G_0 (0 kg ha^{-1} of gypsum). Statistically significant variation was recorded in terms of leaf length due to interaction effect of gypsum and levels of salinity. The highest leaf length (517.65) was recorded from S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while lowest leaf length (137.53) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 9).

Table 9. Effects of gypsum on the leaf properties (leaf area, leaf width, leaf length and leaf ratio) of maize

Treatments	Leaf Properties (75 DAS)			
	Leaf Area(cm^2)	Leaf Width(cm)	Leaf Length(cm)	Leaf Ratio
Salinity level (mM)				
0	18120 a	54.36 a	451.45 a	14.49 a
100	5670 b	31.28 b	282.38 b	11.63 b
150	3223 c	24.28 c	198.11 c	10.30 c
CV(%)	25.92	11.46	1.56	4.87
Gypsum levels (kg ha^{-1})				
0	6158 c	27.47 c	210.11 d	9.35 c
150	7864 bc	32.11 c	291.10 c	12.57 b
175	12173 a	47.19 a	381.10 a	14.27 a
200	9822 ab	39.79 b	360.26 b	12.38 b
CV (%)	25.92	11.46	1.56	4.87
Interaction of salinity X gypsum levels				
S_0G_0	12670 bc	39.61 cd	319.31 e	9.94 ef
S_0G_1	16242 b	44.19 c	471.78 c	11.90 cd
S_0G_2	24216 a	74.69 a	517.65 a	12.82 c
S_0G_3	19352 ab	58.94 b	497.06 b	11.86 cd
S_1G_0	4226 d	23.71 fg	173.50 i	9.40 ef
S_1G_1	5075 d	29.15 defg	251.59 g	15.03 b
S_1G_2	7424 cd	37.82 cde	356.77 d	17.92 a
S_1G_3	5956 cd	34.45 cdef	347.64 d	15.63 b
S_2G_0	1580 d	19.09 g	137.53 j	8.69 f
S_2G_1	2274 d	22.98 fg	149.94 j	10.79 de
S_2G_2	4879 d	29.06 defg	268.88 f	12.07 cd
S_2G_3	4158 d	25.97 efg	236.09 h	9.66 ef
CV(%)	25.92	11.46	1.56	4.87

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation

4.2.3.4 Leaf ratio

The ratio of leaf length and leaf width was considerably influenced by the action of salt stress, gypsum application and their interaction effect. Salinity declined the ratio of leaf length and width. However, the highest leaf ratio (14.49) was found from S_0 treatment (0 mM of NaCl i.e., control), and the lowest leaf ratio (10.30) was observed from S_2 treatment (150 mM of NaCl). On the other hand, gypsum application enhanced the ratio in salt-stressed plants (ANOVA Table 7). The highest leaf ratio (14.27) was found from G_2 reatment (175 kg ha^{-1} of gypsum), and the lowest leaf ratio (9.35) was observed from G_0 (0 kg ha^{-1} of gypsum). The highest leaf ratio (17.92) was recorded from the treatment combination of S_0G_2 (0 mM of NaCl + 175 kg ha^{-1} gypsum), while lowest leaf ratio (8.69) was recorded from S_2G_0 (150 mM of NaCl + 0 kg ha^{-1} gypsum) treatment combination (Table 9).

4.3 Effect of gypsum on the physiological traits of maize under saline environment

4.3.1 Relative leaf water content (RLWC)

The RWC was measured in maize leaf at 75 DAS. The RWC was decreased with the increasing of salinity level. However, the highest RWC in leaf (91.20%) was observed from S_0 (0 mM of NaCl i.e., control), while the lowest (64.74%) was found from S_2 (150 mM of NaCl). Under saline conditions plant suffers from osmotic shock due to lower osmotic potential in the soil solution (Islam, 2001). Plant synthesizes different metabolites across the tonoplast to maintain turgor. However, the plant must spend substantial energy to maintain turgor under water deficit conditions (Munns and Termat, 1986).

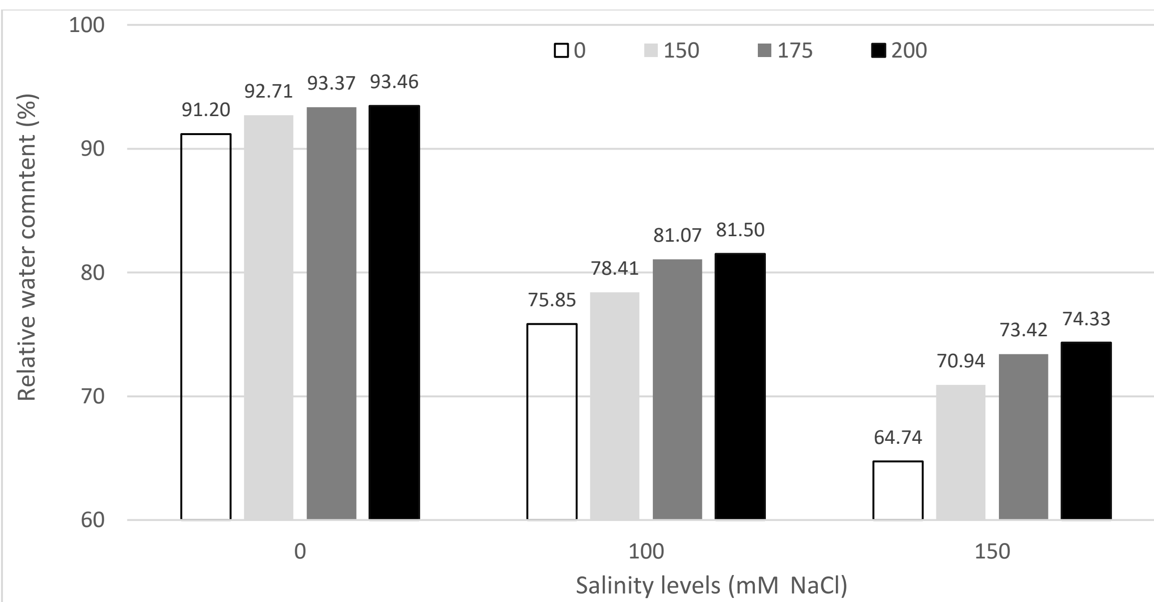

Fig.1. Effect of gypsum on relative water content (RWC) under different levels of salinity

The RWC signifies the water content in plants. In this study, maize was found to be suffer more due to stress than control. Application of gypsum at different concentrations in salt stressed plants significantly mitigated the adverse effects of salt stress. The results revealed that when the concentration of gypsum increase then the RWC of maize also increased in all the treatments. The interaction effect of salinity and gypsum on RWC was varied significantly. The highest interaction (93.46%) was recorded from S_0G_3, while the lowest (64.74%) was recorded from S_2G_0 treatment combination (Fig. 1).

Similar findings was observed by Molazem *et al*. (2012) in study the effect of salt stress on the antioxidant enzyme activities on the leaves of maize in different salinity level showed that with increasing salinity, significant reduction in leaf relative water content was observed.

4.3.2. Water saturation deficit (WSD)

The WSD showed an inverse trend of RWC. The WSD increased with the increase of salinity level in maize. The highest WSD in leaf was observed (35.26 %) from S_2 (150 mM of NaCl), while the lowest (6.54%) was found from S_0 (0 mM of NaCl i.e., control). Gypsum application positively influenced the WSD in salt-stressed and non-stressed plants. The WSD of maize significantly decreased with the increasing gypsum levels. The interaction effect of salinity and gypsum on WSD was varied significantly. The highest WSD (35.26%) was recorded from S_2G_0, while the lowest WSD (6.54%) was recorded from S_0G_3 treatment combination (Fig. 2).

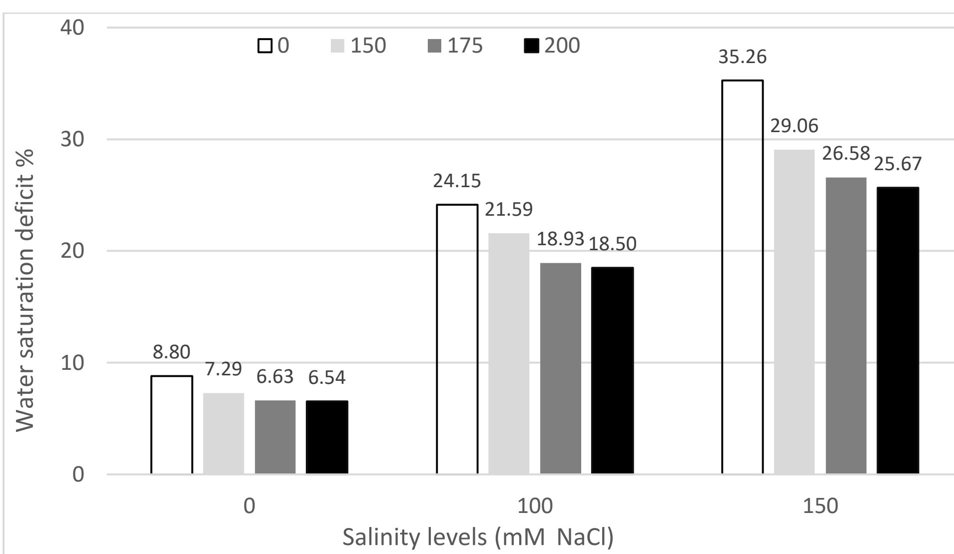

Fig.2. Effect of gypsum on water saturation deficit (WSD) under different levels of salinity

Water deficit may occur as the result of lowered water potential of the soil solution and restricting root water uptake by salt stress. Root injury and death due to ionic toxicity may have affected water uptake by the plants and as a result increased water deficit in the plants. The presence of salt in soil solution decreases the osmotic potential of soil, creating water stress and making it difficult for the plant to absorb water necessary for growth and hence ,decreased leaf water potential (Munns,1993)

4.3.3. Water retention capacity (WRC)

The WRC decreased with increasing salinity level in maize. The highest WRC in leaf (8.02 %) was observed from S_0 treatment (0 mM of NaCl i.e., control), while the lowest (4.42 %) was found from S_2 (150 mM of NaCl).

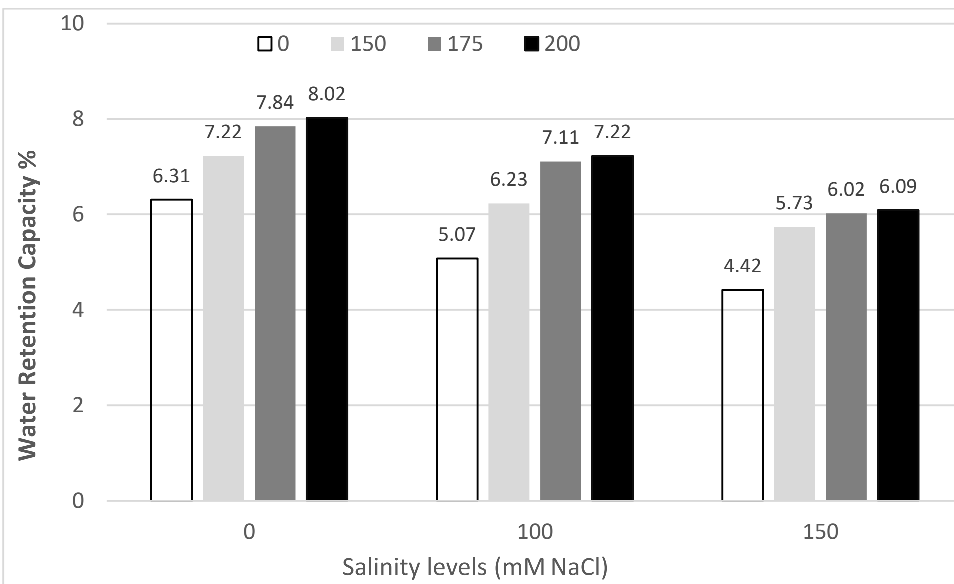

Fig. 3. Effect of gypsum on water retention capacity (WRC) under different levels of salinity

The WRC was varied significantly with the application of gypsum in different concentrations. The WRC of maize increased in salt-stressed plants when the concentration of gypsum was applied. The interaction effect of salinity and gypsum on the WRC was varied significantly. The highest WRC (8.02%) was recorded from interaction effect of S_0G_3, while the lowest WRC (4.42%) was recorded from S_2G_0 treatment combination (Fig. 3). Similar result was reported by Akhtar *et al*. (2013) in wheat, Cramer *et al*. (1989) in barley who concluded that Ca application in plants under salt stress conditions remarkably increased the WRC in plants.

4.3.4. Water uptake capacity (WUC)

The WUC increased with the increase of salinity level in maize. The WUC was higher in stress condition than normal condition. The highest WUC in leaf (1.14 %) was observed from S_2 (150 mM of NaCl), while the lowest (0.27%) was found from S_0 (0 mM of NaCl i.e., control). Application of gypsum in different concentrations attenuated the adverse effects of salt stress, and reduced the values of WUC considerably.

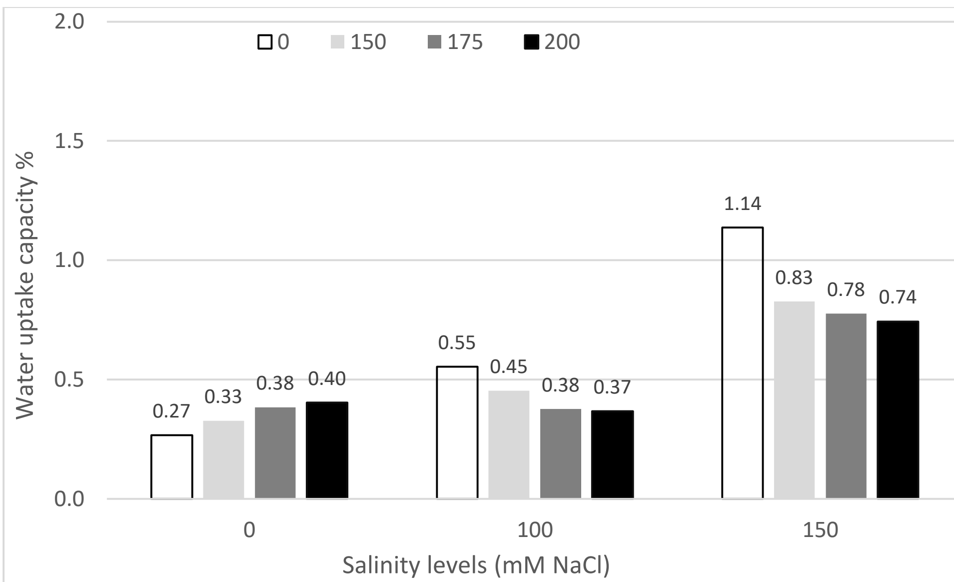

Fig. 4. Effect of gypsum on water uptake capacity (WUC) under different levels of salinity

The interaction effect of salinity and gypsum on WUC was varied significantly. The highest WUC (1.14 %) was recorded from the interaction effect of S_2G_0, while the lowest WUC (0.27 %) was recorded from S_0G_0 treatment combination (Fig. 4). Gypsum modifies soil physical and chemical properties to provide better growing environments for plants. This could, in turn, facilitate plant root exploration into greater soil volumes and to deeper depths of the soil profile resulting in better water and nutrient use efficiency and might reduce nutrient input needs (Dick *et al*., 2006; Watts and Dick, 2014).

4.4 Effect of gypsum on the nutritional traits of maize under saline traits

4.4.1 Sodium (Na^+) content in shoot and root

The interaction effects between salt stress and gypsum on Na^+ content were varied significantly (ANOVA Table 8).

Table 10 Effects of gypsum on Sodium, Potassium and Calcium content in the shoot of maize under saline environment at different DAS

Treatments	Shoot(mg/100g)		
	Na^+	**K^+**	**Ca^{+2}**
	Salinity level (mM)		
0	194.23 c	461.67 a	866.90 a
100	570.10 b	423.42 b	615.58 b
150	599.33 a	419.35 b	485.49 c
CV(%)	1.08	4.16	2.32
	Gypsum levels (kg ha^{-1})		
0	536.73 a	353.69 c	577.28 d
150	480.32 b	452.28 b	619.12 c
175	435.65 c	461.98 ab	648.92 b
200	365.51 d	471.30 a	778.65 a
CV (%)	1.08	4.16	2.32
	Interaction of salinity X gypsum levels		
S_0G_0	226.51 h	395.57 e	782.81 d
S_0G_1	196.85 i	470.71 abc	850.18 c
S_0G_2	195.31 i	488.28 ab	887.85 b
S_0G_3	158.23 j	492.13 a	946.77 a
S_1G_0	674.46 b	335.37 f	568.51 i
S_1G_1	606.34 d	436.75 d	598.21 h
S_1G_2	557.83 e	446.27 cd	632.52 g
S_1G_3	441.78 g	458.99 bcd	663.09 f
S_2G_0	709.22 a	330.14 f	380.51 k
S_2G_1	637.76 c	449.37 cd	408.98 j
S_2G_2	553.80 e	451.39 cd	426.38 j
S_2G_3	496.53 f	462.77 abcd	726.09 e
CV(%)	1.08	4.16	2.32

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

The amount of Na^+ increased with increasing the salinity levels. BARI Hybrid Maize 9 contained higher amount of Na^+ at all salinity levels. The highest Na^+ content (709.22 mg/100 g) in maize shoot was observed at S_2G_0 (150 mM NaCl + 0 kg ha^{-1} gypsum) and the lowest of that (158.23 mg/100 g) at S_0G_3 (0 mM NaCl + 200 kg ha^{-1} gypsum) (Table 10). In case of root the highest Na^+ content (487.59 mg/100 g) was observed at S_2G_0 (150 mM NaCl + 0 kg ha^{-1} gypsum) and lowest (167.79 mg/100 g) at S_0G_3 (0 mM NaCl + 200 kg ha^{-1} gypsum) (Table 11). Salt stress significantly influenced the Na^+ content in Maize. Similar findings were reported by Karmoker *et al*. (2008) who reported that NaCl salinity in the range of 50 to 200 mM increased Na^+ accumulation in the root and shoot of 7, 14 and 21 day-old maize seedlings. Similar findings were also reported by Haq *et al.* (2009) and Akram *et al*. (2007).

4.4.2 Potassium (K^+) content in shoot and root

The interaction effects between salt stress and gypsum on K^+ content were varied significantly (ANOVA Table 8). The amount of K^+ decreased in BARI Hybrid Maize 9 with increasing the salinity levels and decreasing concentration of gypsum levels. BARI Hybrid Maize 9 contained lower amount of K^+ at higher salinity and lower gypsum levels. The result showed that K^+ content in seed decreased with increasing salinity. The relative reduction in K^+ accumulation due to salinity was more in S_2G_0 treatment combination in shoot (Table 10) and also in root (Table 11). Salt stress negatively affected the K^+ in maize. The present result is in line with the results of Karmoker *et al*. (2008) who stated that K+ accumulation decreased with the increase in NaCl concentration from 50 to 200 mM in the root and shoot of maize. Datta *et al.* (1996) also reported that an increase in salinity level decreased K^+ content.

Table 11. Effects of gypsum on Sodium, Potassium and Calcium content in the root of maize under saline environment at different DAS

Treatments	Root (mg/100g)		
	Na^+	**K^+**	**Ca^{+2}**
Salinity level (mM)			
0	282.87 c	237.84 b	800.19 b
100	362.52 b	269.27 a	818.45 a
150	407.74 a	224.18 c	773.78 c
CV(%)	1.04	1.23	0.98
Gypsum levels (kg ha^{-1})			
0	431.81 a	159.38 d	715.92 d
150	376.69 b	219.57 c	769.65 c
175	330.22 c	259.07 b	829.04 b
200	265.46 d	337.04 a	875.27 a
CV (%)	1.04	1.23	0.98
Interaction of salinity X gypsum levels			
S_0G_0	359.71 e	181.16 i	720.86 fg
S_0G_1	332.22 f	209.73 h	801.60 d
S_0G_2	271.74 i	269.78 d	806.98 d
S_0G_3	167.79 j	290.70 c	871.30 b
S_1G_0	448.14 b	168.88 j	717.69 g
S_1G_1	357.14 e	220.89 g	775.97 e
S_1G_2	335.57 f	267.86 d	858.86 b
S_1G_3	309.25 h	419.46 a	921.28 a
S_2G_0	487.59 a	128.10 k	709.21 g
S_2G_1	440.71 c	228.10 f	731.39 f
S_2G_2	383.34 d	239.58 e	821.28 c
S_2G_3	319.34 g	300.96 b	833.23 c
CV (%)	1.04	1.23	0.98

Data followed by same letter are not significantly different by DMRT test at $p < 0.05$, CV, Co-efficient of variation.

4.4.3. Calcium (Ca^{2+}) content in shoot and root

The amount of Ca^{2+} decreased in BARI Hybrid Maize 9 with increasing the salinity levels and decreasing concentration of gypsum levels (ANOVA Table 8). BARI Hybrid Maize 9 contained lower amount of Ca^{+2} at higher salinity and lower gypsum levels. The highest Ca^{2+} content (946.77 mg/100 g) in maize shoot was observed at S_0G_3 (0 mM NaCl + 200 kg ha^{-1} gypsum), and the lowest of that (380.51 mg/100 g) at S_2G_0 (150 mM NaCl + 0 kg ha^{-1} gypsum) (Table 10). In case of root the highest Ca^{+2} content (921.28 mg/100 g) was observed at S_1G_3 (100 mM NaCl + 200 kg ha^{-1} gypsum) and the lowest of that (717.69 mg/100 g) at S_1G_0 (100 mM NaCl + 0 kg ha^{-1} gypsum) (Table 11).

It has been reported earlier that excessive Na^{+} induces Ca^{2+} deficiency having an appearance like lesions on aerial plant parts along with a reduction in leaf blade dry weight (Maas and Grieve, 1990), which supports in this findings.

CHAPTER V

SUMMARY AND CONCLUSION

A pot experiment was conducted at the Agronomy Shade House, Dept. of Agronomy, Hajee Mohammad Danesh Science & Technology University, Dinajpur from November, 2021 to March, 2022 to determine the alleviation of salt stress through Gypsum in BARI Hybrid Maize-9. The experiment was laid out in Completely Randomized Design (CRD) with three replications. In the present investigation, seeds of BARI Hybrid Maize-9 were used as planting materials. Plants were grown under saline and non-saline conditions. The experiment was having two factors. One was Factor A: Three salinity levels such as S_0= Control, S_1= 100 mM NaCl and S_2= 150 mM NaCl, and another was Factor B: which was designed by four levels of gypsum, G_0 = Control, G_1 = 150 kg ha^{-1} gypsum, G_2 =175 kg ha^{-1} of gypsum and G_3 = 200 kg ha^{-1} of gypsum. In all treatments, 20 seeds were sown in each pot and later thinned to 6 plants per pot at 20 DAS. Gypsum doses were applied at two intervals. Intercultural operations like thinning, weeding etc. were done when necessary. Results obtained from this investigation are given below:

Salt stress adversely affected the plant height and no. of leaves. This decline was noticed at all developmental stages (50 DAS, 75 DAS and 100 DAS), and the decreases was more in plants growing under 150 mM of NaCl as compared with 0 kg ha^{-1} of gypsum. However, the tallest plant was in 0 mM of NaCl and 175 kg ha^{-1} of gypsum. The decreases in fresh weight and dry weight (leaf, stem, root) and leaf area index including leaf area, leaf width, leaf length and leaf ratio under salt stress led to reduction in all growth traits of maize.

Salt stress causes significant reduction in physiological parameters. Under NaCl stress, the relative water content (RWC) and water retention capacity (WRC) reduced. On the other hand, the water saturation deficit (WSD) and water uptake capacity (WUC) increased. Application of gypsum ameliorated the adverse effects of salt and contributed in the increase in above two parameters. In this case, 150 mM of NaCl causes higher reduction, and 0 mM of NaCl causes lower reduction in RWC and WRC, and adverse result was found in WSD and WUC.

The interaction effects between salt stress and gypsum on the Na^+ content was adverse of K^+ content and Ca^{+2} content in shoot and root of maize. Under 150 mM NaCl and no application of gypsum the Na^+ ion was more, whereas the K^+ ion increases inversely. The highest Ca^{+2} content in maize shoot was observed at 0 mM of NaCl and 200 kg ha^{-1} gypsum, and the lowest was recorded at S_2G_0 combination. In case of root, the highest combination was recorded S_1G_3, and the lowest was at S_1G_0 combination.

Considering the situation of the present experiment, it can be concluded that the S_0G_2 (0 mM NaCl + 175 kg ha^{-1} gypsum) is the best treatment under non-saline condition as well as in saline condition. Maize can be grown in moderate saline condition (100 mM of NaCl) along with the application 175 kg ha^{-1} of gypsum it can be also be grown up to 150 mM of NaCl stress condition.

However, the study was done under NaCl-induced salt stress conditions but for more confirmation it is induced to conduct further studies in the southern part of Bangladesh for regional compliance and other performance under natural saline condition.

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APPENDICES

Appendix I: Morpho-physio-chemical properties of soil (collected before sowing of seeds) of the experimental field.

A. Morphological characteristics of the soil

Constituents	Characteristics
Location	Agronomy shade house, Department of Agronomy ,Hajee Mohammad Danesh Science and Technology University, Dinajpur
Agro-ecological zone	Old Himalayan Piedmont Plain (AEZ-1)
Geographical position	$25^0$38N latitude and $88^0$41E longitude
General Soil type	Non-calcareous dark grey floodplain
Parent materials	Old Brahmaputra River borne deposit
Land type	Medium high land
Elevation	37 meter above the mean sea level
Drainage	Well drained
Topography	Fairly level
Soil texture	Sandy loam
Soil Color	Dark grey
Flood level	Above flood level

B. Physical properties of the initial soil (0-15 cm depth)

Constituents	Results
Particle size analysis	
Sand (%) (0.2-0.002 mm)	58
Silt (%) (0.02-0.002 mm)	28
Clay (%) (<0.002 mm)	14
Soil textural class	Sandy loam

Source: Results obtained from the mechanical analysis of the initial soil sample (SRDI, Dinajpur)

C. Chemical composition of the initial soil (0-15 cm depth)

Characteristics	Value (%)
pH (Soil: water = 1: 1.25	5.41
Organic matter	1.48
Organic carbon	0.72
Total N	0.08
Available P (ppm)	11.20
Exchangeable P (meq)	0.10
Exchangeable Ca (meq)	2.48
Exchangeable Mg (meq)	2.29
Available S (ppm)	17.29
Available B (ppm)	0.13
Available Zn (ppm)	0.90
Available Fe (ppm)	51.90
Available Mn (ppm)	12.13

Source: Results obtained from the chemical analysis of the initial soil sample (SRDI, Dinajpur)

Appendix II: Monthly recorded of air temperature, rainfall, relative humidity and sunshine at the experimental site

Months	Temperature (^{0}C)		Relative humidity (%)	Rainfall (mm) Total	Sunshine (hr) (Total)
	Minimum	Maximum			
November 2021	10.51	20.81	60.45	2.12	5.23
December 2021	8.95	22.40	62.14	0.00	3.43
January 2022	13.98	28.19	66.69	0.00	5.73
February 2022	18.81	31.91	73.52	8.30	6.64
March 2022	25.3	37.0	70.00	7.42	6.14

Source: Bangladesh Meteorological Department (Weather Research Station) Rajbrti, Dinajpur

ANOVA Table 1**: Analysis of variance (mean square) of the data for plant height (PH) of maize**

Source of variation	**df**	**PH(cm)**		
		50 DAS	**75 DAS**	**100 DAS**
Factor A	**2**	**2109.74**	**3691.73**	**4675.68**
Factor B	**3**	**747.94**	**1618.27**	**1464.79**
Factor AB	**6**	**230.66**	**153.51**	**110.18**
Error	**22**	**8.66**	**3.09**	**5.12**

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

ANOVA Table 2**: Analysis of variance (mean square) of the data for number of leaves of maize**

Source of variation	**df**	**Number of leaves**		
		50 DAS	**75 DAS**	**100 DAS**
Factor A	**2**	**7.5833**	**6.0833**	**22.8611**
Factor B	**3**	**28.9907**	**29.4074**	**26.0000**
Factor AB	**6**	**0.3241**	**0.7130**	**0.5278**
Error	**22**	**0.3864**	**0.2121**	**0.7854**

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

ANOVA Table 3**: Analysis of variance (mean square) of the data for fresh weight of total leaves and stem of maize**

Source of variation	**df**	**TLFW**			**SFW**		
		50 DAS	**75 DAS**	**100 DAS**	**50 DAS**	**75 DAS**	**100 DAS**
Factor A	**2**	**148.327**	**229.109**	**264.357**	**129.950**	**553.023**	**877.695**
Factor B	**3**	**21.421**	**36.698**	**19.627**	**40.010**	**73.197**	**193.537**
Factor AB	**6**	**3.014**	**2.318**	**3.204**	**4.433**	**13.977**	**19.901**
Error	**22**	**0.015**	**0.093**	**0.045**	**0.196**	**2.553**	**0.270**

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

ANOVA Table 4**: Analysis of variance (mean square) of the data for fresh weight of root of maize**

Source of variation	**df**	**RFW**		
		50 DAS	**75 DAS**	**100 DAS**
Factor A	**2**	**16.632**	**17.721**	**13.465**
Factor B	**3**	**3.795**	**8.373**	**8.572**
Factor AB	**6**	**0.540**	**0.339**	**0.378**
Error	**22**	**0.064**	**0.002**	**0.002**

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

ANOVA Table 5**: Analysis of variance (mean square) of the data for dry weight of total leaves and stem of maize**

Source of variation	df	TLDW			SDW		
		50 DAS	75 DAS	100 DAS	50 DAS	75 DAS	100 DAS
Factor A	2	4.609	8.558	19.986	1.728	3.868	6.015
Factor B	3	0.696	3.395	4.161	0.521	0.371	3.460
Factor AB	6	0.163	0.331	0.499	0.218	0.005	0.066
Error	22	0.001	0.002	0.135	0.002	0.002	0.003

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

ANOVA Table 6**: Analysis of variance (mean square) of the data for dry weight of root of maize**

Source of variation	df	RDW		
		50 DAS	75 DAS	100 DAS
Factor A	2	1.0256	3.415	4.427
Factor B	3	0.134	0.770	0.787
Factor AB	6	0.036	0.398	0.261
Error	22	0.001	0.001	0.0001

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

ANOVA Table 7**: Analysis of variance (mean square) of the data for leaf area index of root of maize**

Source of variation	df	LAI			
		Leaf area	Leaf width	Leaf length	Leaf ratio
Factor A	2	7.658E+08	2973.00	199733	55.082
Factor B	3	6.033E+07	677.54	53745	37.794
Factor AB	6	1.220E+07	123.32	2815	6.127
Error	22	5446773	17.63	24	0.349

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

ANOVA Table 8**: Analysis of variance (mean square) of the data for Na^+, K^+ and Ca^{+2} of maize**

Source of variation	df	Shoot			Root		
		Na^+	K^+	Ca^{+2}	Na^+	K^+	Ca^{+2}
Factor A	2	612492	6543.0	451123	47970.6	6415.0	6053.2
Factor B	3	47107	26864.0	67951	44820.7	49921.0	43421.0
Factor AB	6	5126	290.1	14768	1842.1	4126.1	1948.9
Error	22	24	327.4	232	13.3	8.9	61.3

df= degrees of freedom, Factor A= Salt, Factor B= Gypsum, Factor AB=Salt & Gypsum

Appendix XI: Some photographs of my research works