

**MITIGATION OF SALT STRESS THROUGH GYPSUM IN
MUNGBEAN (BARI MUNG-8)**

A THESIS

BY

MST. REBECA ISLAM

Student No. 1601077

Session: 2021-22

Thesis Semester: July-December, 2022

MASTER OF SCIENCE (M. S.)

IN

AGRONOMY



**DEPARTMENT OF AGRONOMY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY
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DEPARTMENT OF AGRONOMY
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DECEMBER 2022



*Dedicated
To
My Beloved
Parents and All
Well Wishers*

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ABSTRACT

A pot experiment was conducted at the Agronomy Pocket House, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur from March, 2022 to May, 2022 to determine the alleviation of salt stress through Gypsum in Mungbean. The experiment was single factorials which comprised of salinity level 75mM and four levels of gypsums 15 mM, 30 mM, 45 mM and 60 mM. The experiment was laid out in Completely Randomized Design (CRD) with three replications comprised six treatments viz., i) T₁ (0 mM NaCl + 0 mM gypsum), ii) T₂ (75 mM NaCl + 0 mM gypsum), iii) T₃ (75 mM NaCl + 15 mM gypsum), iv) T₄ (75 mM NaCl + 30 mM gypsum), v) T₅ (75 mM NaCl + 45 mM gypsum), vi) T₆ (75 mM NaCl + 60 mM gypsum). In the present investigation seeds of BARI Mung-8 was used. Plants were grown under saline and non-saline conditions. Twenty seeds were sown in each pot and later thinned to 8 plants per pot. The data which were collected during the experiment are plant height (cm), number of leavesplant⁻¹, number of branchesplant⁻¹, fresh and dry weight of plant parts (leaf, stem and root) (g), chlorophyll content (chl-a, chl-b and total chl a+b), plant water status (RWC, WSD, WRC, WUC) of plant parts (leaf), pod length (cm), number of pods plant⁻¹, number of grain pod⁻¹, 100 seed weight (g), seed yield plant⁻¹ (g), stover yield plant⁻¹ (g), biological yield plant⁻¹ (g), harvest index (%), and nutritional properties (Na, K, Ca, N and protein) of seeds . The recorded data were analyzed where mean difference was compared by DMRT. Gypsum doses were applied at two intervals. Intercultural operations like thinning, weeding etc. were done when necessary. The result revealed that different growth parameters, yield and yield contributing characters and bio-chemical parameters of mungbean variety BARI Mung-8 were significantly influenced by salinity and different levels of gypsum. In saline condition, T₅ (75 mM NaCl + 45 mM gypsum) showed the highest plant height, fresh and dry weight (leaves, stems and roots), better water status and chlorophyll content, maximum number of pods plant⁻¹(15.00), highest pod length (4.73 cm), highest number of grains pod⁻¹(6.33), highest value of 100 grains (4.60 gm), highest grain yield (1.17g plant⁻¹), highest stover yield (1.31g plant⁻¹), highest biological yield (2.48 g plant⁻¹), highest harvest index (41.17%). These results indicated that application of gypsum could alleviate the adverse effects of salinity and increase the tolerance of mungbean to salinity. On the other hand, T₂ treatment (75 mM NaCl without gypsum) showed the lowest value for all parameters. Therefore, Mungbean (BARI Mung-8) can be successfully cultivated under moderate salt stress (7.5 dS/m or 75 mM NaCl stress) with the addition of 75 mM gypsum.

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LIST OF ABBREVIATIONS

AEZ	:	Agro Ecological Zone
BARI	:	Bangladesh Agricultural Research Institute
CRD	:	Completely Randomized Design
CV	:	Co-efficient Of Variance
DAS	:	Days After Sowing
df	:	Degrees of Freedom
DW	:	Dry Weight
<i>et al.</i>	:	And other
FAO	:	Food and Agriculture Organization
FW	:	Fresh Weight
HSTU	:	Hajee Mohammad Danesh Science and Technology University
g	:	gram(s)
LSD	:	least Significant Difference
PH	:	Plant Height
QPM	:	Quality Protein Mungbean
RWC	:	Relative Water Content
SRDI	:	Soil Resources and Development Institute
WSD	:	Water Saturation Deficit
WRC	:	Water Retention Capacity
WUC	:	Water Uptake Capacity

CHAPTER I

INTRODUCTION

Pulses are the essential protein source for the majority of the people of Bangladesh. Pulses are considered as poor man's meat due to their easy and cheapest source of protein in the south Asian countries. It is easily digestible, good for all age groups, and does not have any adverse effect on known diseases. The soup is widely known as Dal in south Asian countries, including Bangladesh (Islam, 2001). Pulses contain protein about twice as much as cereals. It also contains amino acid, lysine, which is generally deficit in food seeds. The area under pulse crops in Bangladesh is 0.823 million hectares with a production of 1.645 million tons (AIS, 2021).

Mungbean [*Vigna radiata* (L.) Wilczek] is one of the most important pulse crops of global economic importance (Islam *et al.*, 2017a). It belongs to the family Fabaceae and sub-family Papilionaceae. It is originated in the South and southeast Asia (India, Myanmar and Thailand) (Poehlman, 1991). Mungbean is cultivated on over 6million ha in the warmer regions of the world and is one of the most important pulse crops (Rao *et al.*, 2016). It is widely grown in India, Pakistan, Bangladesh, Myanmar, Thailand, Philippines, China and Indonesia (FAO, 2005). Among the pulse crops, mungbean has a special importance in intensive crop production systems of the countries for its short growing period (Islam *et al.*, 2017b). Mungbean is regarded as the best of all pulses from the nutritional point of view and which comprised of 51% carbohydrate, 26% protein, 4% minerals and 3% vitamins (Uddin *et al.*, 2009). It is considered as a quality pulse in the country but production per unit area is very low (1270 kg/ha) as compared to other countries of the world (AIS, 2021). Mungbean is one of the most emergent pulse crops of Bangladesh. It ranks 1st position both in acreage and production among the pulses grown in Bangladesh (AIS, 2021).

Mungbean is very sensitive plant to salt (Islam, 2001). Being a leguminous crop, it is capable of fixing atmospheric nitrogen through symbiotic relationship with soil bacteria and improve the soil fertility (Islam *et al.*, 2021). Like other legumes, it fixes atmospheric nitrogen (58-109 kg/ha) in symbiosis with *Rhizobium* which not only meet its own nitrogen need, but also benefits following crops (Ali and Gupta, 2012). It can be grown in late winter and summer season in Bangladesh. Mungbean gives higher yield under summer planting than late winter season (Singh and Yadav, 1978). Summer mungbean can tolerate a high temperature

exceeding 40°C and grows well in the temperature range of 30-35°C. Mungbean is also reported to be drought tolerant and can also be cultivated in areas of low rainfall (Islam *et al.*, 2022). The green plants can also be used as animal feed and the residues as manure.

Environmental stresses like salinity adversely affect the the growth and productivity of crop plants. (Islam *et al.*, 2011). It's a global problem which results in the reduction of agricultural crop production. Plant growth inhibition varies due to nature and properties of salts in each climatic zone, but severity is confined in arid and semi-arid zones (Rengasamy, 2006). Although soil salinity occurs predominantly in arid and semi-arid regions, it has been found in all the climatic zones (Munns and Tester, 2008). The arable land is becoming transferred into saline (1-3% per year) either due to human activity which accounts nearly 20% of the irrigated agricultural land (Saha *et al.*, 2010; Hasanuzzaman *et al.*, 2013). Salinity greatly affects the agriculture of the world, especially in the coastal areas. In Bangladesh, over 30% of the net cultivable areas lie in the coastal area, which approximately 53% are affected by varying degrees of salinity (Haque, 2006). The severity of salinity in these areas increases with the desiccation of the soil. Bangladesh has 3million hectares of land affected by salinity, mainly in the coastal and south-east districts, with electrical conductivity (EC) values ranging between 4 and 16 dS/m (Zaman and Bakri, 2003).

Salinity affects plant growth by inducing water deficit, low uptake and accumulation of essential nutrients, and high accumulation of toxic ions such as Na⁺ and Cl⁻ in plant cells (Munns, 2005; and Islam *et al.*, 2011). The water deficit in plant mainly occurs due to a decrease in the osmotic potential of the soil solutes, which makes it difficult for roots to extract water from their surrounding media (Jaleel *et al.*, 2007). Moreover, the problem in salt affected land is increasing due to low quality water usage for irrigation, improper drainage in canal-irrigated wetland agro-ecosystems, entry of seawater in coastal areas during cyclones, and higher accumulation of salts in the root zone due to considerable evaporation of water and insufficient leaching of ions due to low rainfall in arid and semi-arid regions (Munns and Tester, 2008). Many of studies reported the negative effects of salinity on physical and chemical properties of the soil, as well as the activity of soil microorganisms (Lakhdar *et al.*, 2009). Salt stress imposes substantial adverse effects on the performance and physiology of the crop plants, which eventually leads to plant death as a consequence of growth arrest and metabolic damage (Hasanuzzaman *et al.*, 2012). Ahmed (2009) observed fewer seeds per pod and lower grain weight under salinity stress in mungbean. Saline condition may effects the Legume-*Rhizobium* symbiosis in nodulation because of its osmotic and ionic effects.

Bangladesh is an over populated country. Agricultural land area is decreasing day by day and therefore it is very much important to produce extra food for limited land to mitigate the required food supply problem (Islam *et al.*, 2017a,b). Due to increasing demand of cereals, farmers are interested to allocate good soils for cereals instead of legumes resulting cultivation of legumes is pushing to the problems soils including saline soils. But its productivity is low due to soil salinity. So, selection of crop or a variety of a crop for saline area considered as an important management option to minimize yield loss due to salinity. Numerous attempts have been made to improve the salinity tolerance of a crop variety by traditional breeding programs (Duan *et al.*, 2008), but the progress to develop such salt-resistance plants is very slow and commercial success is limited due to mutagenic responses of the adaptive process. Nevertheless, the negative effects of salt stress on plants depend on plant genotypes, severity and exposure time of salinity and environmental factors (Islam and Gregorio, 2013). An alternative approach for coping with salinity could, therefore be an extragenous application of growth regulators which diminish salinity effect in plant to a tolerable level. Gypsum is a soil amendment or conditioner, is known to provide a multitude of benefits by promoting soil aggregation and enhancing the soil physical properties. Gypsum can reduce soil dispersion, prevent soil crusts formation, promote better seedling germination, facilitate better water infiltration and soil aeration, improve crop water relations, increase soil drainage, reduce soil erosion and runoff, and also improve water quality by decreasing phosphorus (P) losses from soils (Amezketta *et al.*, 2005; King *et al.*, 2016; Kost *et al.*, 2018). Gypsum can therefore, favorably modify 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 depth 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). However, studies have been conducted the ameliorative effects of gypsum on crop plants under saline conditions but precise information regarding the application of gypsum on mungbean is meager. Therefore, the present study was selected with the following objectives:

- i) To know the mitigating effects of gypsum on mungbean crop under saline conditions, and
- ii) To find out the optimum level of gypsum for mungbean cultivation under saline condition.

CHAPTER II

REVIEW OF LITERATURE

For the improvement of yield and quality of mungbean crop, several reaches have been performed in many countries especially in south-East Asia. The arable land is decreasing day by day due to the increasing salinity level in soil and salinity severely reduced the growth and yield of crops. Gypsum is an important nutrient source which helps not only on successful crop production but also increase crop productivity under saline conditions by mitigating salt stress. The salinity mitigating effects of gypsum in mungbean has not yet been done appropriate level. In this chapter an attempt has been made to review some of the related available information regarding alleviating effects of gypsum under salt stress and its effects on growth, yield and yield components of mungbean and other related crops.

2.1 Effect of salinity on growth, yield and yield contributing characteristics

Sehrawat *et al.* (2015) conducted the experiment with two popular mungbean varieties (Pusa vishal and Pusa ratna) under salt stress (0, 50 and 75mM NaCl) during summer and spring seasons, and significant variations and adaptability among stressed and non-stressed plants were observed in both varieties. Salinity induced osmotic stress severely limited the plant growth, morphology, physiology and yield characteristics during summer. Measured parameters were less affected during spring season. The tolerant variety Pusa vishal exhibited less reduction in plant height, total chlorophyll and carotenoid contents, plant length, leaf area, rate of photosynthesis, number of pods per plant and grain yield at high salinity level as compare to the susceptible variety, Pusa ratna. A delay in pod ripening during spring season resulted in less pod-shattering. The present study may help to execute further research on screening of large mungbean germplasms for salt tolerance during spring season. The germplasm screening may help to identify resistant genotypes for genetic improvement of mungbean for growing in saline soil.

Ahmed *et al.* (2009) conducted an experiment with five mungbean accessions/genotypes with the aim of ascertaining the effect of salt stress on the yield and its component. The decrease in seed yield per plant under salt stress was more pronounced, associated with a reduced number of seed per pod and 100 seed weight. Consequently salt stress was more effective at vegetative, flowering and seed filling stages rather than seed development stage in all the five

accessions/genotypes. Delayed maturity due to salt stress pushes the plant also be desiccation stress causing shriveled seeds.

Sehrawat *et al.* (2013) conducted an experiment and reported that 22 wild relatives of mungbean belong to seven *Vigna* species were screened for salt tolerance under two salinity levels (control and 250mM NaCl) with five replications per treatment. The investigated genotypes exhibited significantly variable response towards salt stress. The adverse effects of salinity on plant growth, branching, leaf size and color, necrosis and chlorosis symptoms were observed visually by taking photographs at regular intervals during the crop season. Salinity caused $\geq 80\%$ up to 100% loss of yield in most of the genotypes that indicated their high susceptibility for salt stress.

Kandil *et al.* (2012) conducted a laboratory experiment in order to study performance of mungbean to salinity stress, and carried out to investigate salinity tolerance of two mungbean varieties (Kawmy-1 and IV 2010) to eight salinity levels i.e. 0, 2, 4, 6, 8, 10, 12 and 14 dS/m of NaCl concentrations. Mungbean (*Vigna radiata* (L.) Wilczek) varieties were compared for germination efficiency and seedling characters. Results indicated that mungbean IV 2010 variety recorded the highest percentages of final germination, germination index (%), seedling vigor index, energy of germination, mean germination time (day), coefficient velocity, abnormal seed percentage, root and shoot length, root fresh and dry weight and seedling height reduction. Whilst, the Kawmy-1 variety recorded the highest fresh and dry weight of shoot, and relative dry weight. The highest germination parameters and seedling characters of the two studied varieties under control treatment. The obtained results suggested that the two varieties registered a decrease in the percentage of germination and seedlings growth at higher NaCl concentrations. Increasing salinity concentrations significantly reduced germination percentage, seedling vigor index, coefficient of velocity, mean germination time, shoot and root length, shoot and root fresh and dry weight. It could be concluded that germination efficiency i.e. final germination percentage, germination index, energy of germination, mean germination time, abnormal seed percentage, root and shoot length, seedling total fresh and dry weight, dry weight reduction and shoot length reduction were gradually decreased significantly when salinity increased.

Sehrawat *et al.* (2013) conducted an experiment and reported that high salt accumulation resulted in decreased osmotic potential of soil solution eliciting water stress in plants and further interactions of the salts with mineral nutrition caused nutrient imbalance and

deficiencies, oxidative stress or even pathology eventually lead to plant death as a result of physiological changes, metabolic damage and growth arrest.

Khan *et al.* (2010) conducted an experiment and reported that effect of NaCl stress on yield and various physiological parameters (leaf area, osmotic potential, glycine-betaine, total sugars and chlorophyll contents) was studied in seven wheat genotypes (Lu-26s, Sarsabz, Bhattai, KTDH22, Khirman, B-7012 and Bakhtawar) grown under two salinity levels (1.5 and 12 dS/mNaCl) in the cemented tanks having river sand. Seeds were allowed to germinate under normal condition and salinity treatments were imposed after one week of germination. Salinity reduced the grain yield, leaf area and chlorophyll contents however it resulted in an increase in the osmotic potential, glycine-betaine and total sugar contents. The results clearly indicated that under salt stress, genotypes with higher leaf area, osmotic potential, glycine-betaine, total sugar and chlorophyll contents, had more grain yields as compared to the genotypes with lower values for these attributes. The tolerant genotypes also maintained higher leaf area, osmotic potential, glycine-betaine, total sugar and chlorophyll contents under saline conditions.

Mohammed *et al.* (2007) conducted a pot experiment to determine the effect of salt stress (NaCl 0.0, 100, 200 and 300 mM) on growth and metabolic activities of mungbean plants. Pre-soaking the seeds in GA (200 mg/L) was shown to ameliorate the deleterious effects of salinity in the majority of cases. The results revealed that NaCl treatment induced drastic reduction in growth characteristics of mungbean plant through decreasing the shoot and root lengths, number of lateral roots and number of leaves, total area of leaves as well as fresh and dry weights of shoot and root of mungbean plants. Furthermore, this treatment markedly decreased the pigment contents, photosynthetic activity, reducing sugars and sucrose contents as well as total soluble-N, total-N and protein-N contents, nucleic acids content, peroxidase and catalase activities and rate of respiration as O uptake and CO evolution. On the other hand, salt stress appeared to increase polyamine (putrescine, PUT), spermidine Spd, spermine Spm and total polyamines, RNase and polyphenol oxidase activity. Moreover, salt stress increased sodium and chlorine contents and decreased potassium, calcium and magnesium levels in root and shoot of mungbean plants. In the majority of three cases pre-soaking the seeds in 200 mg/L GA caused partial decrease in the deleterious effects of salinity in all parameters of this study.

Kabir *et al.* (2005) conducted a green house experiment with three kinds of nitrogen fertilizer (13.3, 40, 60kg ha^{-1}) and two kinds of salt treatments (0, and 75 mM NaCl) in of mungbean (BARI Mung-3) under natural light and reported that salt treatment markedly deteriorated the moisture status of the plant body, and the relative water content, xylem exudation rate, and water potential decreased significantly. Yield and yield components, except the number of seeds per pod, were reduced by salt treatment, but these declines were mitigated by high-concentration nitrogen fertilizer. The sodium content decreased with salt treatment, and the Na content increased greatly. The content of the former four tended to increase, while the Na content tended to decrease with the high-concentration nitrogen fertilizer treatment. From the above results, it was clarified that the application of high-concentration nitrogen fertilizer improved the water condition and nutrient absorption of plants under salinity stress, and increased the yield rice field.

Manasa *et al.* (2017) conducted an experiment to screen 40 mungbean lines under salinity stress (150 and 300 mM NaCl). The results shown a considerable reduction in growth and yield performances of both tolerant and susceptible lines, but a few lines displayed relatively a better biomass and pod yield on par with non-stressed control plants. Based on seedling and whole plant level tolerance, a few tolerant (EC 693357, 58, 66, 71 and ML 1299) lines were identified for further investigation. Efforts are underway to use these identified tolerant lines as donor source for salinity breeding program to introgress with high yielding popular varieties.

Gogile *et al.* (2013) conducted an experiment of nine cowpea genotypes under four NaCl concentrations (0, 50, 100 and 200 mM) during the seedling stage in greenhouse condition. The analyzed data revealed highly significant ($p < 0.001$) variation among cowpea genotypes, treatments and their interactions. It is found that salt stress significantly decreased root length, shoot length, seedling shoot and root weight of cowpea genotypes. The extent of decrease varied with genotypes and salt concentrations. Most genotypes were highly susceptible to 200 mM NaCl concentration. The correlation analysis revealed positive and significant association among most of the parameters. The study revealed the presence of broad intra specific genetic variation in cowpea varieties for salt stress with respect to their early biomass production.

Dutta *et al.* (2014) conducted an experiment to know the effect of different salinity levels on germination, seedling growth, seedling vigour and chlorophyll contents of five mungbean

[*Vigna radiata* (L.) Wilczek] cultivars (Pusa Baisakhi, PS7, B-105, Pusa-105 and Suniana), and reported that the percentage of germination, seedling growth parameters and seedling vigour index were found to decrease under salinity stress. Salinity caused reduction in chlorophyll contents, chlorophyll a/b ratio and chlorophyll stability index.

Ashraf *et al.* (2013) conducted a pot experiment to appraise the inhibitory effects of salt stress on biochemical attributes in the three mungbean cultivars (NCM-209, NCM-89 and NM-92). Salt stress caused a significant decrease in plant height, shoot relative water contents, photosynthetic pigments, endogenous levels of K^+ and K^+/Na^+ ratios and increase in cellular levels of H_2O_2 , MDA, Na^+ and Cl^- . Salt stress markedly also affected different yield attributes in all mungbean cultivars. Again cultivar NCM-209 exhibited less inhibitory effects of salt stress on different growth attributes. Salt stress resulted in a marked increase in the activities of antioxidant enzymes (superoxide dismutase, peroxidase, catalase and ascorbate peroxidase) in mungbean cultivars. It could be inferred from data of antioxidant enzymes that mungbean cultivars cannot be categorized as salt tolerant or sensitive on the basis of a single antioxidant enzyme.

Aslam *et al.* (2017) conducted an experiment and reported that the effects of salinity are highly diverse and depends on large number of factors like amount, intensity and duration of salinity and crop growth stages. Increased uptake of toxic ions couples with limited uptake of essential minerals resulting in significant reduction in enzymatic activity and disturbance in cell metabolism. Moreover, increased solute potential and reactive oxygen species inside the cells act as secondary damaging factors to physiological process and plant anatomy. Plants struggle to avoid or escape the stress by closing the stomata which results in stunted growth, wilting of plants and reduced productivity. Germplasm can be evaluated using different methods to access the salinity tolerance and their further administration in different breeding programs could develop tolerant cultivars.

Abdel-Haleem *et al.* (2015) conducted an experiment with five mungbean genotypes under four salinity levels viz. Normal water 153 as control, 2500, 3500 and 4800 ppm. Germination percentage over control decreased insignificantly with increasing salinity levels. On contrary, salinity significantly reduced shoot length, root length, seedling fresh weight and seedling dry weight, relative water content, ion leakage and chlorophyll content. There were genotypic differences among the test genotypes in response to salt stress exposure. The results indicated that salinity levels had a significant effect on all of studied traits. While, the interaction

between genotypes and water salinity levels were significant with root length, seedling fresh weight, seedling dry weight, relative water content, ion leakage and chlorophyll content. Germination percentage and shoot length, exhibited insignificant effect. All studied traits for cowpea seedlings decreased with increasing salinity.

Rafiq *et al.* (2006) conducted the experiments to investigate the effect of salt stress on morpho-biochemical response of wheat cv. Uqab-2000. Seeds were given different priming treatments like hydro priming, chilling, kinetin, $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ and controlled (with no treatment). After priming treatments the seedlings were grown under normal and salt stress (NaCl 125 mM) for 8-days in petridishes at $25 \pm 1^\circ\text{C}$ in an incubator, the results revealed that generally all treatments except hydro priming increased the morphological growth of the seedlings, particularly chilling, kinetin, and calcium chloride showed a significant difference compared to control. An overall increasing trend in the catalase activity (units/ mg fresh weight) was observed except kinetin treatment in normal and chilling in saline conditions. The profound increase in activity of catalase was observed after chilling and hydro priming in normal and saline, respectively. However, all seed priming treatments decreased the ascorbic acid concentration under salinity, while reverse was true for normal conditions. Application of salt stress have overall substantial negative effect on all the visual growth and biochemical parameters, However seed priming treatments tend to alleviate the adverse effects of salinity.

Ahmed *et al.* (2016) conducted an experiment to investigate the effect of salinity (0.5, 1.6, 2.8, 3.5, 3.8 and 4.3 ECe dSm^{-1}) on *Cajanus cajan* by observing vegetative plant growth like height, fresh and dry biomass, moisture, relative growth rate (RGR) and specific shoot length (SSL), reproductive (number of flowers, pods, seeds and seed weight) and some biochemical parameters (chlorophylls, carotenoids, sugars and proteins), and reported that the plant height, biomass, SSL and RGR linearly decreased under saline conditions. Leaf pigments increased (chlorophylls) or maintained (carotenoids) at 1.6 dSm^{-1} and subsequently decreased in higher salinity. Low moisture content and succulence along with more accumulation of soluble sugars and proteins may be attributed to leaf osmotic adjustments at low salinity. Salinity adversely affect reproductive growth of *C. cajan* where production of flowers, pods, number of seeds and seed weight were significantly reduced. Present study provides basic information related to plant growth, seed yield and some biochemical attributes, which suggest *C. cajan* as a salt sensitive leguminous crop. However, detailed information is required to understand the eco-physiological responses of this plant under field and green house conditions.

Jabeen *et al.* (2003) conducted an experiment to find out the effect of salt stress on *Vigna mungo* and reported that the germination was significantly declined at salinity levels of 5.0 dS/m and above in the laboratory experiment while in the pot experiment germination significantly reduced at salinity levels of 7.5 dS/m and above. Radical and plumule lengths were also significantly reduced at 5.0 dS/m and higher levels of NaCl. Plant height, number of branches and number of leaves significantly decreased at 10.0 dS/m higher levels of salinity. The number of seeds was significantly dwindled at 7.5 dS/m and above. Similarly, chlorophyll contents were also significantly low 7.5 dS/m and higher concentrations. It was concluded *Vigna mungo* might not show promising growth and productivity in saline habitats. However, under mild saline conditions it might be grown not only to supplement the crop yield, but also as a source of fodder and soil reclamation measure.

Alrahman *et al.* (2005) conducted an experiment under salt stress in vitro. Microshoots were grown on Murashige and Skoog (MS) solid proliferation media containing 2.89 μ M GA₃. Salinity was induced by incorporating 0, 50, 75, or 100 mM of NaCl to the culture media. Microshoots were exposed to direct and gradual shock of salinity. Gradual salt shock was induced by gradually transferring microshoots every week to different NaCl concentration from 0 to 50 to 75 to 100 mM (starting from the control and ending with 100 mM NaCl). Growth parameters (shoot length, fresh shoot weight, dry shoot weight, root length, and root number) were generally reduced with elevated salt level in the direct and gradual salt shock. This reduction was less impaired in the gradual salt shock treatment. Root length was enhanced at 50 mM NaCl in both salt shock treatments. Leaf osmotic potential was significantly reduced (more negative) with increasing salinity. Na concentration was increased in salinized microshoots, K and Ca were reduced with elevated salinity and this reduction was less pronounced in the gradual salt shock. Increasing salt stress significantly reduced N to similar levels in the direct and gradual salt shock treatments. K/Na ratio decreased in salinized microshoot as compared with control and gradually microshoot showed higher K/Na ratio than directly salinized microshoot. Increased NaCl level slightly increased P and Mg concentration in the gradually salinized microshoots and significantly decreased P and Mg concentration in the directly salinized microshoots. Increasing salinity increased ash percent and reduced soluble protein percent, fat, and fiber in microshoots under both salt shocks. Moisture percent significantly decreased in directly salinized microshoots whereas it was maintained constant in gradually salinized microshoots. Carbohydrates content decreased at 50 and 75 mM NaCl, but increased at 100 mM NaCl. Elevated salinity

significantly reduced microshoot crude protein content and increased proline and reducing sugars content. Microshoots accumulated higher moisture, reducing sugars, soluble protein, crude protein, proline and lower fat and carbohydrates when gradually salinized than when directly exposed to salt stress.

Hasanuzzaman *et al.* (2005) carried out an experiment at the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh with the objective of verifying the effects of different salinity levels on the germination, growth and yield of four irrigated rice (*Oryza sativa* L.) cultivars. The experiment was performed with 6 NaCl concentrations viz. 0, 30, 60, 90, 120 and 150 mM. It was observed that seed germination, plant height, tiller number and leaf area index are negatively influenced by different salinity levels in all the rice varieties. All the yield components that is number of panicles, panicle length, spikelets per panicle, filled grain and grain weight also significantly decrease with the increased salinity stress. An increase of NaCl concentration up to 150 mM decreased 36-50% of the grain yield of all the four rice varieties. Among the varieties BRRI dhan41 showed better performance at salinity stress up to a certain level.

Mudgal *et al.* (2009) conducted an experiment with 10 genotypes of chickpea, three cultivars were screened in saline soils; two of them are kabuli (PUSA-1053, PUSA-939) and one desi types (BG-256). The seeds of the different cultivars were inoculated with *Rhizobium* sp. strain G-118 and the plants were grown in the greenhouse. After 12 days when symbiosis establishes, saline water of varying concentrations (0, 4, 8, 12, 16 dSm⁻¹) NaCl, Na₂SO₄, CaCl₂ were supplied to the seedlings. Results showed that plant growth, nodulation and nitrogenase activity were more severely affected in cultivar BG-256 under salinity treatments than cultivars PUSA-1053 and PUSA-939. Nodule mass and number was enhanced under salt stress in PUSA-1053 and PUSA-939. Phosphoenolpyruvate carboxylase (PEPCase) activity increased significantly in the nodules of tolerant cultivars under salt stress at all harvests, and this was clearly related to the salt treatments. Salinity reduced leaf chlorophyll and Rubisco activities in all the three cultivars. Salt stress limits photosynthetic efficiency, nitrogen fixation and carbon metabolism. Alteration in the nodular metabolism seemed to be directly responsible for nitrogen fixation by the salt tolerant cultivars. The present study reveals that under saline stress tolerant cultivars are more capable of nodulation which helps to attain higher nitrogen fixation by symbiosis than the sensitive ones.

Salinity is a term used to describe a condition when the presence of salt concentration is higher in soil and water, such as sodium chloride (NaCl), magnesium sulfate (MgSO₄), calcium sulfate (CaSO₄) and bicarbonate (HCO₃⁻). Ghosh *et al.* (2015) examined the physiological and biochemical responses to increasing NaCl concentrations, along with low concentrations of gibberellic acid or spermine, either alone or in their combination, were studied in mungbean seedlings. Similarly oxidative stress markers such as proline, malondialdehyde (MDA) and hydrogen peroxide (H₂O₂) contents also increased as a result of progressive increase in salt stress. Combined application of NaCl along with low concentrations of either gibberellic acid (5µM) or spermine (50µM) in the test seedlings showed significant alterations, that is, drastic increase in seedling elongation, increased biomass production, increased chlorophyll content and significant lowering in all the antioxidant enzyme activities as well as oxidative stress marker contents in comparison to salt treated test seedlings, leading to better growth and metabolism.

Hossain *et al.* (2008) conducted a pot experiment at the Bangladesh Institute of Nuclear Agriculture (BINA) experimental farm, Mymensingh, to observe the response of three mungbean genotypes (Binamoog-4 and two-advanced line BMX 92007-3 and BMX 94010-11) under different salt stress (control, 3.89 and 7.82dSm⁻¹). All morpho-physiological characters such as plant height, number of leaf, leaf area, yield contributing characters such as number of pods plant, number of seeds pod, 1000-seed weight, harvest index were reduced with the increase of salinity levels as compared to control. Plant height and yield attributes like number of pods plant, number of seeds pod, 1000 seed weight, harvest index were the highest in advanced line BMX 94010-11 compared to those in Binamoog-4 and advanced line BMX 92007-3.

Nahar *et al.* (2016) and Shelley *et al.* (2016) reported that many nutrients are unavailable for plant such as nitrogen, phosphorus, copper, zinc and decrease potassium, calcium and magnesium into plants, causing significant yield loss due to salinity.

Generally, salinity causes two main stresses in plants viz. osmotic stress (1st phase) and ionic stress (2nd phase). Osmotic stress occurs when the salt concentration exceeds the tolerance level of plants around root zone in soil, after that salt reaches in order leaves which increase the amount of Na⁺ into plants and causes ionic stress, thus interruption the metabolic process and possess cell death (Munns and Tester, 2008; Hasanuzzaman *et al.*, 2013 a,b).

During salinity stress physiological drought occurs in plants because of higher level of salt concentration in soil decrease the water potential, therefore in spite of large amount of water contain in soil profile plants cannot uptake water from soil (Lee *et al.*, 2004; Reddy *et al.*, 2017). Salt accumulation in plant leaves causes toxicity and as like drought it reduces the total photosynthetic leaf area which decreases the supply of assimilates into growing tissues and this effect on yield (Hasanuzzaman *et al.*, 2013b). There are many literatures reported that drought and salinity stress reduced the plant height, leaf area and dry mass in rice (Ashfaq *et al.*, 2012; Ishak *et al.*, 2015), wheat (Wu *et al.*, 2015; Mujtaba *et al.*, 2016), maize (Khan *et al.*, 2015) and barley (Ahmed *et al.*, 2013a). Drought and salinity stress increased osmotic effect on plants due to the reduction of soil water potential surrounding the root zone, which interrupts the ability of water uptake from soil to maintain turgor pressure (Sabir *et al.*, 2009; Ahmed *et al.*, 2015).

Higher intracellular Na⁺ concentration is an additional problem in plant under salinity stress, thereby RWC also decreased in plant. Ueda *et al.* (2013) were carried out an experiment with two rice cultivars namely CFX 18 (salt-tolerant) and Juma 67 (salt-sensitive). They reported that leaf area, root-shoot fresh and dry weight, leaf water content and leaf water potential significantly decreased in Juma 67 than CFX 18 with increased salinity, therefore, CFX 18 considered more salt tolerant. According to Ueda *et al.* (2013), it can be suggested that under higher salinity concentration plants sequester more NaCl in leaf tissue more than normally occurs, thus, lower osmotic potentials and reduction in the root hydraulic conductance decreases water flow rate root to shoot, causing water stress in the leaf tissue.

Ahmed *et al.* (2013b) observed the combined stress of drought and salinity in relative water content, water potential decreased in cultivated barley, whereas, unchanged in Tibetan wild barley compare to control. In a previous study, Muranaka *et al.* (2002) observed that the photosynthesis rate was decreased in two wheat (*Triticum aestivum* L.) at two stages under 100 mM salt stress. At first photosynthesis was decreased slowly without any visible changes in photochemical and after that in second stage photosynthesis was reduced together with impaired the energy generation efficiency of photo-system two (PSII).

Furthermore, reduction of photosynthesis in plants due to the salinity stress is related to reduce production of ATP through impairing the electron transport system (Curtiss *et al.*, 2011). Ion toxicities of Na⁺ and Cl⁻ reduced the growth and photosynthesis of plants through impaired the photosynthetic apparatus reported by Tavakkoli *et al.* (2011).

Wang *et al.* (2018) observed in their experiment that specific ionic toxicity of Na⁺ and Cl⁻ decreased the photosynthetic rate, CO₂ concentration and also impaired the electron transport system in rice (*Oryza sativa* L.) crop leaves. Similarly, Mahlooji *et al.* (2018) conducted a field experiment with three barley (*Hordeum vulgare* L.) genotypes viz. Morocco (salt-sensitive); Nosrat (semi-salt-tolerant); Khatam (salt-tolerant) to evaluate the effect of high salinity on net photosynthesis, transpiration rate and stomatal conductance. Under high salinity stress, salt tolerant genotype Khatam had maximum net photosynthesis rate and stomatal conductance than those of Morocco and Nosrat genotypes.

According to Mahlooji *et al.* (2018), it was concluded that although high salinity stress decreased the net photosynthesis but salt-tolerance of the Khatam genotype was associated with an avoidance of Na⁺ accumulation in aboveground parts and facilitating higher photosynthetic rate.

Chlorophyll is a major chloroplast component of photosynthesis; therefore, chlorophyll contents have a correlation with the photosynthetic rate. Bhusan *et al.* (2016) observed in an experiment that under salinity stress chlorophyll b and total chlorophyll contents of rice cultivars decreased but chlorophyll a was increased significantly. It has been reported that reduction of chlorophyll contents under salinity stress depend on plant species because of chlorophyll contents increase in salt-tolerant cultivars, decrease in salt-sensitive cultivars (Khan *et al.*, 2009).

Salinity stress not only limits the nutrients uptake in plant but also increases the Na⁺ and Cl⁻ ions in plants which inhibit the plant growth (Ahmed *et al.*, 2015). Both of Na⁺ and Cl⁻ ions disturb the specific transport system of nitrate (NO₃⁻), phosphate (PO₄³⁻) and sulfate (SO₄²⁻) ions into plants (Maathuis, 2006). However, according to Rahman *et al.* (2016) the calcium (Ca), magnesium (Mg), manganese (Mn) and zinc (Zn) content decreased significantly in rice (*Oryza sativa* L.) seedlings under salinity stress.

Zeng *et al.* (2001) observed salinity stress affects plants growth at different stage and they have exposed the rice crop to salinity at the time of seedling, first leaf, third leaf, panicle initiation (PI) and booting stages respectively. They point out salinity stress before PI reduced shoot dry weight and grain yield.

Harris *et al.* (2010) carried out a greenhouse experiment with barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) to observe the effect of salinity on growth and yield. They

observed at high salinity stress grain number reduced by 31 and 22% in barley and wheat crop, respectively, and also grain size reduced in both crops. Plants yield also correlated with spikelet fertility and grain filling.

Ghassemi *et al.* (2009) conducted an experiment in 2007 to evaluate grain filling (four harvests), yield and yield components of three soybean cultivars (Zan, L17 and Williams) under saline (3, 6 and 9 dS/m NaCl) conditions in the green house. Six seeds were sown in each pot filled with 900 g perlite. Grain filling rate also varied among cultivars and was positively associated with the maximum grain weight. However, variation in grain filling duration had little effect on grain weight of soybean cultivars. Decreasing protein yield per plant with increasing salinity were mainly attributed to the large reductions in grain yield per plant under saline conditions. It was concluded that soybean is a sensitive plant to salinity stress and both environment and genotype are responsible for the variation in yield and yield components of this crop.

Sohrabi *et al.* (2008) conducted an experiment to evaluate the effects of different level of Na salinity (0, 3, 6 and 9 dSm⁻¹) on growth, yield and yield component of Kabuli (Hashem and Jam) and Desi (Kaka and Pirooz) chickpea cultivars. They reported that salinity reduced the plant growth, flower, pod and seed number and seed weight. Four chickpea cultivar have different responses to salinity and Kabuli cultivars seemed to have a greater capacity for salt tolerance compared to Desi cultivars. Hashem cultivar has the highest salinity tolerance among all cultivars.

2.2 Effect of gypsum on the growth, yield and yield contributing characteristics

Chaudhari *et al.* (2015) conducted a field experiment on mungbean at Coastal Soil Salinity Research Station, Danti (Gujarat) to study the effect of gypsum and integrated nutrient management on soil physicochemical properties of partially reclaimed coastal salt affected soils of South Gujarat during rabi season. In all 10 treatment combinations arising out of two levels of gypsum (G0 : No gypsum and G1 : gypsum @2 t/ha) and five levels of integrated nutrient management (F1 : 100 % RDF: 20:40:00 NPK kg/ha, F2 : 100 % RDF + Bio-compost @ 5 t/ha + Bio fertilizer : *Rhizobium* + PSB @ 1.25 l/ha, F3 : 75 % RDF + Bio-compost @ 5 t/ha + Bio fertilizer : *Rhizobium* + PSB @ 1.25 l/ha, F4 : 50 % RDF + Bio-compost @ 5 t/ha + Bio fertilizer : *Rhizobium* + PSB @ 1.25 l/ha, F5 : Bio-compost @ 5 t/ha) were tested in factorial RBD. The results revealed that application of gypsum @ 2 t/ha significantly lower down the pH, ESP and bulk density of the soil, and improved the water

stable aggregates. Soil salinity and pH value did not influence significantly due to addition of organics, but there was significant improvement in WSA and at the same time bulk density of soil decreased.

Phogat *et al.* (2021) conducted this modelling study and focuses on developing alternative management options that can reduce the potentially harmful impacts of RW use on the irrigation of wine grapes and almonds. The multi component UNSATCHEM add-on module for HYDRUS-1D was used to evaluate the impact of long-term (2018–2050) use of irrigation waters of different compositions: good-quality low-salinity (175 mg/L) water (GW), recycled water with 1200 mg/L salinity (RW), blended water of GW and RW in the 1:1 proportion (B), and monthly (Alt1) and half-yearly (Alt6) alternate use of GW and RW. The management options include different levels of annual gypsum applications (0, 1.7, 4.3, and 8.6 t/ha soil) to the calcareous (Cal) and hard red-brown (HRB) soils occurring in the Northern Adelaide Plain (NAP) region, South Australia. Additional management scenarios involve considering different leaching fractions (LF) (0.2, 0.3, 0.4, and 0.5) to reduce the salinity build-up in the soil. A new routine in UNSATCHEM to simulate annual gypsum applications was developed and tested for its applicability for ameliorating irrigation-induced soil sodicity. The 1970-2017 period with GW irrigation was used as a warm up period for the model. The water quality was switched from 2018 onwards to reflect different irrigation water qualities, gypsum applications, and LF levels. The data showed that the GW, B, Alt1, and Alt6 irrigation scenarios resulted in lower soil solution salinity (EC_{sw}) than the RW irrigation scenario, which led to increased EC_{sw} values (4.1-6.6 dS/m) in the soil. Annual gypsum applications of 1.7, 4.3, and 8.6 t/ha reduced pH, SAR, and ESP in both soils and reduced the adverse impacts of irrigation, especially in surface soils. A combination of water blending or cyclic water use with 3.8 t/ha annual gypsum applications showed promise for the SAR and ESP control. Additionally, irrigation with RW, a 0.2 LF, and annual gypsum applications limited the harmful salinity impacts in the soils. However, in the RW irrigation scenario, EC_{sw} and ESP at the bottom of the crop root zone (90-120 cm depth) in the HRB soil were still higher than the wine grape and almond salinity thresholds. Thus, annual amendment applications, combined with the long-term use of blended water or cyclic use of RW and GW, represent a sustainable management option for crop production at the calcareous and hard red-brown soils.

Daur *et al.* (2013) evaluated this study to know the effect of gypsum and brassinolide (Br) application on soil properties and berseem (*Trifolium alexandrinum* L.) growth and yield

during two subsequent growing seasons (2008/09 and 2009/10). A randomized complete block experimental design with a split-plot arrangement was used, where gypsum (0 and 5 t ha⁻¹) was included as a main-plot factor and Br (0, 0.1, 0.2, and 0.3 mg L⁻¹ of water) was included as a subplot factor. It was found that gypsum reduced the electrical conductivity (EC) and sodium adsorption ratio (SAR) of the soil, but did not affect soil P^H. Both gypsum and Br had a significant effect on leaf chlorophyll, green and dry fodder yield, and the contents of nitrogen, phosphorus, calcium, and crude protein of berseem. The findings of this study will help to improve the cultivation of berseem in saline soils and may also be applicable to other crops grown under similar conditions.

Khan *et al.* (1992) conducted a greenhouse experiment to evaluate the effects of gypsum, Zn, and intermittent saline irrigation on the growth, yield, and nutrition of rice plants grown in a coastal saline soil. Highly significant effects were detected in the treatments with various levels of salinity, gypsum, Zn, and their interactions on the growth, yield, and nutrition of the rice plants. Gypsum and Zn application significantly reduced the adverse effects of salinity and resulted in the production of the maximum number of tillers and in the tallest plant height. Reduction in grain yield was about 70 and 90% for saline irrigation applied at the rate of 8 and 16 dS/m, respectively compared with tap water irrigation (0.6 dS/m). The combination of gypsum and Zn produced a grain yield about 30, 8, and 20% higher than that of the control at 0.6, 8, and 16 dS/m salinity, respectively. Harvest index was reduced due to saline irrigation but gypsum and Zn were found to increase the harvest index of rice. Nitrogen and P contents of straw decreased with the increase in the salinity levels but gypsum and Zn had an additive effect on the N content. The treatments were found to be significant for the K, Ca, Mg, S, Zn, Na, and Cl contents of the rice plant. The Mg content increased up to 8 dS/m level of salinity. The interactive effects of gypsum and Zn were found to be conducive to the increase of the K, Ca, Mg, S, Zn contents and decrease of the Na and Cl contents of the rice plant even at the highest salinity (16 dS/m) level.

Hafez *et al.* (2015) conducted an experiment to investigate the effects of gypsum applied before sowing (i.e. gypsum and without gypsum) and irrigation interval treatments applied after anthesis (irrigation every 4, 6, 8 days) on chemical characterizations of clay saline-sodic soil. In addition, the effect of these treatments on rice growth, water use efficiency and related parameters and yield were investigated. A significant higher efficiency in reclamation of clay saline-sodic soil was obtained in terms of reducing SAR, Na⁺ and EC when gypsum was applied and water was added every four or six days intervals in comparison to non-

treated soil with gypsum and water added every eight days interval. The highest number of spikelets per panicle, ripened grains percent, grain and straw yields were obtained when rice plants were grown on soil treated with gypsum and irrigated every four and/or six days intervals compared to soil with no gypsum and irrigated every eight days interval. The highest water use efficiency was obtained from rice irrigated every six days interval. In conclusion, it may reduce the hazards of the saline-sodic soil due to application of gypsum which improved soil properties, rice growth and its productivity when plants were irrigated every four or six days intervals. This might be due to the valuable nutrient source of gypsum interns of Ca, which mitigated the toxicity caused by salts in saline soils. Gypsum can also be considered as an effective application for clay saline-sodic soil in the North Delta, Egypt.

Muhammad *et al.* (2007) conducted a study on a farmer's field at village Majokay, Charsadda in Peshawar valley (NWFP), Pakistan during Rabi 2004-05, in order to investigate the effect of gypsum and FYM on the properties of saline-sodic soils and yield of wheat crop irrigated with brackish tubewell water. Treatment combinations were control (T1), FYM @ 20 t per ha (T2), gypsum @ 50% GR (T3), gypsum @ 50% GR + 10 tons FYM per ha (T4), gypsum @ 100% GR (T5) and gypsum @ 100% GR + 10 tons FYM per ha (T6) arranged in RCB design with three replications. Gypsum was calculated on the basis of water gypsum requirement. Results showed that gypsum at half rate and manure individually improved wheat yield, though non-significantly, to the tune of 70 and 45%, respectively over control. Significantly higher increases occurred with their combined application or with gypsum at full rate. The 1000-grain weight showed significant increases with all the treatments over control. Gypsum application at full rate gave 14.3% increase in grain yield than that at half rate. Regarding growth parameters, the effect of manure was non-significant whereas gypsum combined with manure significantly improved growth over control. The maximum increases in the number of spikes m^{-2} , number of leaves $plant^{-1}$, number of grains $spike^{-1}$, grain yield, straw yield, 1000-grain weight and harvest index were 128, 46, 48, 133, 34, 47 and 76%, respectively in case of combined application of gypsum @ 100% GR and manure @ 10 tons per ha.

Reza *et al.* (2001) conducted the field trials with maize-wheat-cotton-wheat crop rotation with three treatments including T1) Application of gypsum by broadcast method, T2) Control (no gypsum application), and T3) Application of gypsum in slots. The results showed that the maximum increase in soil permeability by 220% occurred in slotted area, whereas the infiltration rate increased by 152% with gypsum application by broadcast method. The electrical conductivity of soil (ECe) decreased by 49 and 15% at 0-30 and 30-60 cm depths,

respectively with gypsum applied by broadcasting. On the other hand, application of gypsum in slots reduced ECE of slotted area by 51% at 0-30 and 25% at 30-60 cm depths. In case of slotting method, fewer salts were accumulated at 60-90 cm depth than that of broadcast method. Similarly, gypsum application by broadcast method reduced sodium adsorption ratio (SAR) of soil by 59% at 0-30 cm depth and 8% at 30-60 cm depth. At lower depth of 60-90 cm, SAR was increased by 24%. But gypsum application in slots decreased SAR by 72.

Verma *et al.* (1980) conducted an experiment and they reported that gypsum was applied at 0, 7.1, 14.2, 21.3 and 28.4 tons/ha, and equivalent quantities of pyrites at 0, 3.6, 7.2, 10.8 and 14.4 tons/ha on rice (*Oryza sativa*) and on wheat (*Triticum aestivum*), grown in a highly sodic soil. Both chemicals significantly increased the grain yield of rice and wheat over untreated plots, with gypsum still being significantly better than pyrites. Rice yield showed no reduction up to an exchangeable sodium percentage (ESP) of 55 in the surface soil (0-15 cm), but at 80 it sharply decreased by 50%. Wheat yield sharply decreased above ESP 30 and the crop failed at ESP 50 and above. In rice accumulation of Na above 1.1% and 125 ppm, respectively, in straw and grain reduced yield significantly, and in wheat 0.18% and 50 ppm were critical. The chemical composition of both crops was primarily related to the soil ESP.

Hussain *et al.* (2000) conducted the experiment in the field on a normal soil. Brackish tube well water was used for irrigating wheat and rice crops without any amendment and with gypsum (equal to sodium contents of irrigation water; and two times its sodium contents). Wheat and rice crops were grown from Rabi 1995-96 to Rabi 1998-99. Grain and paddy yield along with EC, SAR and pH of the soils were recorded. Use of brackish water without any amendment resulted in an increase in EC and SAR of the soil, and caused a decrease in crop yield. Use of the same water in combination with two times its sodium contents resulted in normal yield of both the crops without any harmful effect on the soil. Gypsum equal to sodium contents of the irrigation water proved comparatively less effective.

Nayak *et al.* (2013) conducted this study and they reported that efficacies of mined gypsum and phosphor gypsum (PG), when applied at equivalent doses, were compared for sodic soil reclamation and productivity of rice-wheat system. Application of PG, followed by karnal grass as first crop, resulted in the greatest reduction of soil pH and ESP followed by PG applied at 10 Mg ha⁻¹ alone. Application of PG at 10 Mg ha⁻¹ resulted in greater yields of both rice and wheat than other treatments. Diethylene triaminepenta acetic acid (DTPA)-extractable micronutrients of PG-treated soil were greater than in mined gypsum-treated soil.

A greater portion of applied P entered the calcium (Ca)-phosphorus (P) fraction in PG-treated soil, which also resulted in more soluble P than the mined gypsum-treated soil. Phospho gypsum effected greater increase in aggregation, soil organic carbon, microbial biomass carbon, and aggregate associated carbon and decrease in zeta potential, leading to increased hydraulic conductivity and moisture retention capacity in soil over mined gypsum-treated soil.

Liu *et al.* (2010) conducted a plot experiment on a saline-sodic soil to investigate the effects of phosphor gypsum amendment on growth, yield and yield components of two rice (*Oryza sativa* L.) cultivars (Dongdao 2 and Changbai 9) in 2009. The amelioration treatments were highly saline-sodic soil (control), phosphor gypsum added at rate of 15, 30 and 45 t ha⁻¹, which are referred to as PG1, PG2 and PG3, respectively. Results from the study show that the application of phosphor gypsum increased grain yield of the both rice cultivars significantly. Average increment in yield was 1.12, 2.47 and 2.98 t ha⁻¹ for PG1, PG2 and PG3 against control, but there was no significant difference between PG2 and PG3. With increasing phosphor gypsum levels from PG1 to PG3, the yield components increased significantly. Generally, the increment was 124, 133 and 202% for individual grain mass m⁻², 1182, 3058 and 4235% for spikelets m⁻², 161,191 and 246% for panicles m⁻², 153, 271 and 343% for filled spikelet percentage, and 4,17 and 21% for 1000-grain weight in PG1, PG2 and PG3, respectively compared with the control. PG2 gave similar results to PG3 in terms of grain yield and yield components. They suggest that phosphor gypsum added at rate of 30 t ha⁻¹ should be adopted in saline-sodic soils of North-East China.

Jawahar *et al.* (2013) conducted a field experiment at Annamalai University Experimental Farm, Annamalai Nagar to evaluate the effect of sources and levels of sulphur on growth and yield of rice fallow blackgram. Sulphur sources viz., single super phosphate, gypsum, elemental sulphur and ammonium sulphate were tried at different levels viz., 0, 20 and 40 kg S ha⁻¹ in this study. The experiments consisted of 12 treatments and were laid out in factorial randomized block design with three replications. Among the sources, gypsum registered its superiority over other sources. With respect of levels, application of 40 kg S ha⁻¹ recorded highest growth (plant height, leaf area index, chlorophyll content, dry matter production and number of branches plant⁻¹), yield components (number of pods plant⁻¹ and number of seeds pod⁻¹) and yield (grain and haulm) of blackgram. This study showed that supplementation of sulphur as gypsum significantly increased the growth and yield of blackgram.

Dhanushkodi *et al.* (2009) conducted a field experiment at Agricultural College and Research Institute, Killikulam, Thoothukudi district of Tamil Nadu during Rabi season (Oct-Feb) 2004-2005 to assess the effect of different sources of sulphur viz., single super phosphate, gypsum, elemental sulphur and magnesium sulphate on growth, yield and quality of blackgram (CO-5). The results indicated that the application of 20 kg sulphur as gypsum significantly increased the growth attributes and yield attributes of blackgram. Application of sulphur as gypsum along with N and P increase the quality attributes such as protein and amino acids like methionine and cysteine.

The effect of soil and foliar application of sulphur was investigated on blackgram in Typic Rhodustalf of pulses growing areas of Madurai district. Gokila *et al.* (2015) conducted a field experiment and laid out in a randomised block design with recommended doses of fertilizer with two levels of different sulphur sources as gypsum, ammonium sulphate and potassium sulphate which were supplied through soil and foliar application. The growth and yield components of blackgram viz plant height (54.7cm), number of leaves per plant (53), number of pods per plant (35), number of seeds per pod (7), 100grain weight (4.81 g), dry matter production (2832 kg/ha), grain yield (1145 kg/ha) and haulm yield (1645 kg/ha) were significantly increased. Among the treatments application of 100 per cent recommended dose of fertilizer (RDF) with potassium sulphate 20 kg/ha plus foliar spray of 0.5% K_2SO_4 increased the growth and yield components of blackgram.

Singh *et al.* (2013) conducted a 2-year-field experiment on response of Indian mustard (*Brassica juncea* L.) and blackgram (*Phaseolus mungo* Roxb.) grown in rotation to sulphur application in acid red loam soils of Bihar plateau, and they revealed an increase in grain yields, crop uptake of sulphur, protein and oil yield of seeds due to application of 60-80 kg S/ha as phospho gypsum or pyrites. Application of 60 kg S/ha increased the grain yield of mustard by 320 kg/ha over the control. The residual effect of 80 kg S/ha was significant in increasing the yield of black gram grain by 200 kg/ha over control. Phospho gypsum as a source of S was superior to pyrites in Indian mustard due to its sulphate sulphur content. Low grade pyrites, on the other hand, showed high residual effect on blackgram. Sulphur application resulted in a linear increase in oil content of mustard and protein content of black gram up to 80 kg S/ha level. Results suggest the need to sulphur application in soils low in available sulphur to boost crop yields and increase oil and protein content of oil seeds and pulses, respectively.

Yadav *et al.* (2018) conducted a field experiment at Narendra Deva University of Agriculture and Technology Kumarganj Faizabad Uttar Pradesh to study the effect of different levels and sources of sulphur on yield, nodulation and quality of black gram. Therefore, the investigation was assessed with two sources of S as gypsum and elemental sulphur with four levels (S @ 0, 20, 40 and 60 kg ha⁻¹). The result revealed that, the maximum grain (10.92 q ha⁻¹) and straw (26.54 q ha⁻¹) were observed at 60 kg S ha⁻¹ which was statistically at par with 40 kg S ha⁻¹. While, gypsum recorded significantly higher grain (10.82 q ha⁻¹) and straw (24.91 q ha⁻¹) yield over elemental sulphur. Quality parameters viz., protein (24.30 %) methionine (8.82, mg g⁻¹), number of nodules(33.99), fresh weight of nodules(0.88 g plant⁻¹) and dry weight of nodules (0.398 g plant⁻¹) recorded maximum with application of 60 kg S ha⁻¹ which was statistically at par with 40 kg S ha⁻¹. Gypsum recorded significantly highest protein and methionine content over elemental sulphur. Therefore, it is concluded that the application 40 kg S ha⁻¹ through gypsum proved to be beneficial for getting maximum yield and quality of black gram.

Basumatary *et al.* (2018) conducted a field experiment to assess the effect of S fertilization on distribution of S in soil and use efficiency on blackgram in subtropical Inceptisol of acidic soil of Assam, India. Five levels of S were applied (0, 10, 20, 30 and 40 kg S ha⁻¹) along with recommended dose of nitrogen, phosphorus and potassium. Available S content gradually decreased with the advancement of crop growth stages and lowest value was observed at 60 DAS. Different S fractions were found to increase with increasing levels of S application and 40 kg S ha⁻¹ resulted the highest content for all S fractions. The grain and stover yield of blackgram increased significantly up to 20 kg S ha⁻¹ which was 95.69% higher over control. Agronomic efficiency, apparent S recovery and recovery efficiency of S were higher at 10 kg S ha⁻¹ and found decreased with increase in level of S.

Yadav *et al.* (2015) conducted an experiment during kharif season of 2010 to study the effect of different levels of added gypsum (0, 100, 200, 300 and 400 kgha⁻¹) with RDF (NPK @ 25:50:20 kg ha⁻¹) on growth and yield of groundnut (*Arachis hypogaea* L.). The results indicated that effect of different levels of gypsum had significant effect on growth and yield of groundnut. Biological growth and yield attributes viz., plant height, number of branches plant⁻¹, number peg, number of nodules, fresh weight of pod, dry weight (pod yield), straw yield were also significantly affected by the application of different levels of gypsum. The highest plant height and number of branches plant⁻¹ at 90 DAS (23.16 cm and 9.80, respectively), number of peg and number of nodules at 90 DAS (22 and 122, respectively),

fresh weight of pod and dry weight (pod yield) (37.88 and 26.10 q ha⁻¹, respectively) and straw yield (37.97 q ha⁻¹) were found by the application of NPK-25:50:20 kg ha⁻¹ + gypsum @ 200 kg ha⁻¹. However, it was evident from the present study that different growth parameters and yield of groundnut were increase significantly with application of gypsum @200 kg ha⁻¹.

Meena *et al.* (2013) conducted a field experiment on loamy sand soil at Agronomy Farm, College of Agriculture, SKRAU, Bikaner during (kharif) season 2008-09. The treatments comprise four levels of sulphur [control, 40 kg S/ha as gypsum, 40 kgS/ha as elemental sulphur and 40 kg S/ha as gypsum + elemental sulphur (1:1)] and four levels of iron (control, 0.5% FeSO₄ foliar spray at 25 and 40 DAS, 0.5% FeSO₄ + 0.5% citric acid solution spray at 25 and 40 DAS and 25 kgFeSO₄/ha as basal application). Application of 40 kg S/ha as gypsum + elemental sulphur (1:1) significant increase in dry matter production and chlorophyll content over control and whereas all three sulphur sources *viz.*, gypsum, elemental sulphur and gypsum +elemental sulphur (1:1) proved statistically at par in respect of dry matter production and chlorophyll content.

Kumar *et al.* (2013) conducted Field trials to observe the effect of sulfur and nitrogen nutrition on storage protein quality in mungbean seeds at maturity. Mungbean seeds of varieties PAU 911 and ML 818 were sown in the experimental fields. Soils were pre supplemented with different sulfur and nitrogen sources either alone or in combinations @ 40 kg/ha. Treatments consisted of T1 (control where neither sulfur nor nitrogen was added), T2 (single super phosphate), T3 (urea), T4 (single super phosphate and urea), T5 (gypsum), T6 (ammonium nitrate) and T7 (gypsum and ammonium nitrate). Different sources of sulfur and nitrogen both alone or in combination significantly increased hundred seed weight, total nitrogen and sulfur content, and decreased N: S ratio in PAU 911 and ML 818 seeds. The protein quality parameters ie crude protein, total soluble protein, sulfur containing amino acids (methionine and cysteine), various protein fractions i.e. albumin, globulin, glutelin and prolamins and sub-fractions of globulin ielegumin and vicilin were significantly increased under various treatments of sulfur and nitrogen. Among various treatments, T5 resulted in higher increase in the various protein quality parameters as compared to other treatments.

Nawange *et al.* (2011) conducted a field experiment during the rabi season 2009-2010 to find out the optimum dose of phosphorus and sulphur on growth, yield attributes and yield of chickpea (*Cicer arietinum* L.). Four levels of P₂O₅ (0, 20, 40 and 60 kg/ha) and three levels

of sulphur (0, 20 and 40 kg/ha), applied through DAP and gypsum, respectively. Application of phosphorus from 0 to 60 kg/ha resulted in linear increase in various growth characters, yield attributing traits, seed and stalk yield of chickpea. The application of 60 kg P₂O₅/ha produced the highest mean seed yield of 1761 (kg/ha) and stalk yield of 2754 (kg/ha). Similarly the levels of sulphur up to 40 kg/ha showed linear increase the growth, yield attributes, seed and stalk yield of chickpea. The application of 40 kg sulphur/ha produced the highest mean seed yield of 1665 (kg/ha) and stalk yield of 2665 (kg/ha).

Soybean is one of the most important legume crops in the world. Fageria *et al.* (2014) conducted two greenhouse experiments to determine the influence of liming and gypsum application on yield and yield components of soybean and changes in soil chemical properties of an Oxisol. Lime rates used were 0, 0.71, 1.42, 2.14, 2.85, and 4.28 g kg⁻¹ soil. Gypsum rates applied were 0, 0.28, 0.57, 1.14, 1.71, and 2.28 g kg⁻¹ soil. Lime as well as gypsum significantly increased grain yield in a quadratic fashion. Maximum grain yield was achieved with the application of 1.57 g lime kg⁻¹ soil, whereas the gypsum requirement for maximum grain yield was 1.43 g kg⁻¹ of soil. Lime significantly improved soil pH, exchangeable soil calcium (Ca) and magnesium (Mg) contents, base saturation, and effective cation exchange capacity (ECEC). However, lime application significantly decreased total acidity [hydrogen (H) + aluminum (Al)], zinc (Zn), and iron (Fe) contents of the soil. The decrease in these soil properties was associated with increase in soil P^H. Gypsum application significantly increased exchangeable soil Ca, base saturation, and ECEC. However, gypsum did not change pH and total acidity (H + Al) significantly. Adequate soil acidity indices established for maximum grain yield with the application of lime were pH 5.5, Ca 1.8 c mol_c kg⁻¹, Mg 0.66 c mol_c kg⁻¹, base saturation 53%, Ca saturation 35%, and Mg saturation 13%. Soybean plants tolerated acidity (H + Al) up to 2.26 c mol_c kg⁻¹ soil. In the case of gypsum, maximum grain yield was obtained at exchangeable Ca content of 2.12 c mol_c kg⁻¹, base saturation of 56%, and Ca saturation of 41%.

2.3 Effect of gypsum in alleviating salt stress

Bello *et al.* (2021) reported that salinity impedes soil and crop productivity in over 900 million ha of arable lands worldwide due to the excessive accumulation of salt (NaCl). To utilize saline soils in agriculture, halophytes (salt-tolerant plants) are commonly cultivated. However, most food crops are glycophytes (salt-sensitive). Thus, to enhance the productivity of saline soils, gypsum (CaSO₄·2H₂O) as well as bio-organic (combined use of organic materials, such as compost and straw with the inoculation of beneficial microbes)

amendments have been continuously recognized to improve the biological, physical and chemical properties of saline soils. $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ regulates the exchange of sodium (Na^+) for calcium (Ca^{2+}) on the clay surfaces, thereby increasing the $\text{Ca}^{2+}/\text{Na}^+$ ratio in the soil solution. Intra cellularly, Ca^{2+} also promotes a higher K^+/Na^+ ratio. Simultaneously, gypsum furnishes crops with sulfur (S) for enhanced growth and yield through the increased production of phyto hormones, amino acids, glutathione and osmo protectants, which are vital elicitors in plants' responses to salinity stress. Likewise, bio-organic amendments improve the organic matter and carbon content, nutrient cycling, porosity, water holding capacity, soil enzyme activities and biodiversity in saline soils. Overall, the integrated application of gypsum and bio-organic amendments in cultivating glycophytes and halophytes is a highly promising strategy in enhancing the productivity of saline soils.

Ahmed *et al.* (2021) conducted a study to evaluate the response of rice to foliar application of phyto hormones salicylic acid (SA@ 10^{-5} M) and L-tryptophan (L-TRP@ 10^{-5} M) singly or in combination and soil-applied gypsum (with and without gypsum) under saline-sodic soil for the consecutive two years (2014-2015). Results showed that combined treatment of phyto hormones (salicylic acid+ L-tryptophan@ 10^{-5} M in 1: 1 ratio) with 50% gypsum requirement of soil significantly ($P \leq 0.05$) influenced growth and yield attributes of rice plants and increased the grain yield by up to 26 and 32.80% during 2014 and 2015, respectively compared with control. Results also demonstrated that individual application of salicylic acid or L-tryptophan improved the behavior of rice plants under salinity stress in comparison to control, however, best results in terms of yield and growth attributes were achieved in response to combined treatment of SA + L-TRP. Higher ameliorative efficiency in the terms of improved E_{Ce}, SAR, pHs, BD and HC were obtained with gypsum@ 50% GR in comparison to without gypsum application. Results highlighted that salinity tolerance of rice plants was enhanced under the cumulative effect of phyto hormones suggesting that salicylic acid and L-tryptophan interact synergistically and proved a good strategy to alleviate salt stress.

Neid *et al.* (2005) conducted a study to investigate the use of sodium chloride (NaCl) as a deicing salt result in high concentrations of ions in roadside soils, which decreases seedling emergence in these areas. Greenhouse experiments performed in soil culture tested the efficacy of three soil fertilizers, gypsum (CaSO_4), potash (potassium chloride, KCl) and potassium nitrate (KNO_3), in alleviating NaCl stress on seedling emergence of three grass species exhibiting a range of salt tolerance, *Poa pratensis* (Kentucky bluegrass), *Bouteloua*

gracilis (blue grama), and *Puccinellia distans* (alkali grass). Two-factor factorial designs were utilized for each species-fertilizer combination. Treatments of 5000 mg/L (0.086 M) NaCl with or without fertilizer, in concentrations that were equal to 0.5, 1, and 2 times the molar equivalent of 5000 mg/L NaCl were applied biweekly. Salt stress on *Poa pratensis* emergence was alleviated by all fertilizers with CaSO₄ having the greatest effect in alleviating NaCl stress and potash and potassium nitrate alleviating stress at lower treatment levels. Emergence of *Bouteloua gracilis* and *Puccinellia distans* was in most cases negatively affected by soil amendments.

Cao *et al.* (2019) conducted a study to measure 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). In general, under untreated soil conditions, continuous saline water irrigation resulted in adverse effects on soil properties (e.g. enhanced Na⁺ and sodium adsorption ratio and reduced nutrient availability) and tomato growth (e.g. the reduction of photosynthesis rate, plant growth rate, plant biomass and fruit yield, and the enhancement of blossom-end rot in tomato fruit). However, these adverse effects of continuous saline water irrigation were efficiently alleviated by the application of FGD gypsum and/or SC. The application of co-composted FGD gypsum-SC resulted in the highest fruit yield and the lowest blossom-end rot under continuous saline water irrigation. Plant straw co-composted with FGD gypsum can improve soil properties, maintain crop yields and enhance fruit quality under continuous saline water irrigation.

Mel *et al.* (2019) conducted field experiments in the Africa Rice research field located in the Senegal River delta (16° 11' N, 16° 15' W) to study the effects of three management options of fertilization e.g. (i) nitrogen, phosphorus, and potassium fertilization: NPK; (ii) NPK combined with zinc: NPK-Zn, and (iii) NPK combined with gypsum: NPK-gypsum on the soil salinity level, the nutrient uptake and the productivity of different rice cultivars. The whole objective of this study is to determine how zinc or gypsum associated to NPK fertilizer

can improve the growth and productivity of rice crop in saline soil. Results showed that the initial soil salinity level was reduced rapidly in plots treated with gypsum. The leaf-K/Na ratio, agronomic nitrogen use efficiency (ANUE), and grain yield of rice cultivars under the salinity stress were improved by the NPK-gypsum and NPK-Zn options relatively to the NPK option, suggesting that NPK-gypsum and NPK-Zn are suitable management options in reducing adverse effect of low K/Na, low ANUE as well as to improve rice yield under salinity stress

2.4 Effect of salt stress on ions content

Hossain *et al.* (2008) carried out a pot experiment at the Bangladesh Institute of Nuclear Agriculture (BINA) experimental farm, Mymensingh and observed the response of three mungbean genotypes (Binamoog-4 and two advanced line BMX 92007-3 and BMX 94010-11) under different salt stress (control, 3.89 dSm⁻¹ and 7.82 dSm⁻¹). They reported that all the content of Na⁺ in leaves increased with increasing salinity levels. Potassium content in leaves was not varied among the genotypes but leaves of Binamoog-4 contain the highest amount of K⁺ compared to that in BMX 94010-11 and BMX 92007-3, and among the genotypes advanced line BMX 94010-11 was found as relatively salt tolerant.

Essa (2002) conducted an experiment to determine the effect of salinity on leaf mineral contents using three soybean cultivars, Lee, Coquitt, and Clark 63. They were planted in soils of different salinity levels (0.5, 2.5, 4.5, 6.5 and 8.5 dSm⁻¹). The cultivar Lee was less affected by salinity stress than Coquitt and Clark 63. Salinity stress induced a significant increase in leaf sodium (Na⁺) and chloride (Cl⁻) in all cultivars. However, the cultivar Lee maintained lower Na⁺ and Cl⁻ concentrations, a higher potassium (K⁺) concentration and a higher K⁺/Na⁺ ratio at higher salinity levels than Coquitt and Clark 63. This study suggests that Lee is the most tolerant cultivar, and that there is a relationship between the salt tolerance of the cultivar and macronutrient accumulation in leaves.

Turner *et al.* (2013) conducted an experiment in a glasshouse in Perth, Western Australia, to find out 55 genotypes of chickpea subjected to 0, 40, and 60 mM NaCl. Results revealed that the increased salt tolerance, as measured by yield under salinity or relative yield under saline conditions, was positively associated with higher pod and seed numbers, and higher shoot stover. The concentrations of sodium ion in the seed were significantly higher in the sensitive (106 μmol g⁻¹ DM of sodium) than in the tolerant (74 μmol g⁻¹ DM) genotypes.

Bhuiyan *et al.* (2007) conducted a pot experiment at the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh during the period from February to May 2005 to evaluate the effect of different levels of salinity (control, 2dSm⁻¹, 4dSm⁻¹ and 6 dSm⁻¹) on mineral ion content of four mungbean genotypes (BARI Mung-6, BARI Mung-3 and two advance line, MB-46 and MB-300). Na⁺ content in leaves increased and K⁺, Ca²⁺, Mg²⁺ contents decreased with increasing salinity levels. The advanced line MB-46 contained less amount of Na⁺ and higher amount of K⁺, Ca²⁺, Mg²⁺ compared to the other genotypes.

Patel *et al.* (2010) conducted a study to investigate the impact of salt stress on leaf ions accumulation in three Indian cultivars *viz.*, Akshay-102, Gomti vu-89 and Pusa Falguni of pea cowpea. The electrical conductivity (EC) of the soil was 0.75 dSm⁻¹ and the NaCl treatments increased it to 2,4,6,8 and 10 dSm⁻¹. The results showed that salinity induced a significant increase in Na⁺ concentrations, while reduced the accumulation of K⁺ and Ca²⁺ in leaves of all the cultivars.

Amira and Qados (2010) arranged an experiment with different levels of salinity on mungbean and noticed that salinity stress induced significant increase of Na, Cl, Ca and Mg and decreased N, P and K contents significantly.

Sohrabi *et al.* (2008) conducted an experiment to evaluate the effects of different level of Na salinity (0, 3, 6 and 9 dSm⁻¹) on growth, yield and yield component of Kabuli (Hashem and Jam) and Desi (Kaka and Pirooz) chickpea cultivars. They reported that with an increase in salinity, the underiable effect of Na⁺ was visible and reached the highest value at 9 dSm⁻¹ in all cultivars. Four chickpea cultivars have different responses to salinity and the Kabuli cultivars seemed to have a greater capacity for salt tolerance compared to Desi cultivars. Hashem cultivar has the highest salinity tolerance among all cultivars.

CHAPTER III

MATERIALS AND METHODS

A pot experiment was carried out under a level of imposed soil salinity with four levels of gypsum to examine the salt alleviating effects of gypsum in mungbean, and to find out the optimum level of gypsum to combat salt stress in mungbean. The materials used and methodology followed in the experiment has been presented in this chapter. The description of different materials used and the methodology followed during the experimental period are narrated below:

3.1 Experimental location and duration

The experiment was carried out at Agronomy Pocket house, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh. The experiment was conducted during the Kharif-1 season (5th March- 3rd May), 2022.

3.2 Soil

The soil was collected from Agronomy Research Field, Department of Agronomy, HSTU, Dinajpur. This soil belongs to Ranishankal series under Old Himalayan Piedmont Plain (AEZ 1). The soil was sandy loam in texture having PH 5.52, and medium in organic matter. The soil samples were analyzed in the Soil Resource Development Institute (SRDI), Dinajpur. The morphological, physiological and chemical characteristics of the soil have been presented in Appendix I.

3.3 Climate

The weather data including temperature, rainfall and relative humidity during the period of experimentation of Dinajpur district was recorded from the meteorological station of Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur, Bangladesh. The climate in Dinajpur has been presented in appendix II.

3.4 Experimental material

The variety of mungbean used in the experiment was BARI Mung-8, which was released by Bangladesh Agricultural Research Institute (BARI) in 2015. The variety is very popular due to its unique properties such as can be grown in the year round (Rabi, Kharif-1 and Kharif-2), short life span (58-60 days), higher plant height (55-60 cm), higher pods per plant, larger grain size (TSW 25-32 g), deep yellow grain color, highly tolerant of yellow mosaic virus

and leaf spot disease and higher grain yield (1.6-1.7 t ha⁻¹). The seeds were collected from Bangladesh Pulse Research Institute situated in Ishwardi, Pabna. The seeds were healthy, vigorous well matured and free from other crop seeds and inert materials.

3.5 Preparation of soil and filling of pots

A total of 18 plastic pots were prepared with 10 kg per each pot with the combination of air dried soil on 1st March, 2022. Plant parts, inert materials, visible insects and pests were removed from soil by sieving. Collected soil was dried under sun 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 design and treatments

The research work comprised as one salinity level (75 mM NaCl), and four levels of gypsum (15, 30, 45 and 60 mM CaSO₄.2H₂O, which composed six treatments combination altogether viz., T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. The experiment was set up with completely randomized design (CRD) with three replications. Thus total 18 experimental pots were placed in ambient air at the Pocket House premises, Department of Agronomy, HSTU, Dinajpur.

3.7 Fertilizer application in the pot

The required amount of fertilizers was calculated on the basis of Fertilizer Recommendation Guide of BARI. According to BARI the required primary fertilizer doses of urea, TSP and MP @ 40, 80, and 40kg/ha, respectively were used, and the amount of fertilizers per pot 0.25g, 0.45g and 0.25g, respectively. All the fertilizers were weighed by the digital balance very carefully and they were applied as basal fertilizers.

3.8 Application of NaCl

The required amount of NaCl was applied in the pot during application of water as per treatment.

3.9 Seed treatment and sowing of seeds in the pot

The seeds were treated with Bavistin (0.3%) and after preparing the pots, 20 seeds of BARI Mung-8 were sown carefully on 5th March, 2022 manually in pot. Pots were irrigated with

fresh water (control pots) and saline water according to salt treatments after emergence of seedlings.

3.10 Intercultural operations

Intercultural operations were done very carefully. Thinning was done to give the plant proper space. During thinning weeding was also done. During weeding the soil crust was broken to give proper aeration to soil.

3.10.1 Thinning

After three days of sowing seeds germination was started. Thinning was done in each pot by keeping 8 healthy seedlings as to maintain optimum plant population in each pot.

3.10.2 Irrigation and weeding

Irrigation was done as per requirements with saline water based on treatment. At pre-flowering stage the intensity of weeds was increased. The hand weeding was done as when necessary to keep the pots free from weeds.

3.10.3 Plant protection measures

Plant protection measures were done whenever it was necessary.

3.10.3.1 Insect pests

Pod borer attacked at mature stage, and they affect the seeds by boring and consuming the pods and seeds. Karate was applied to remove the pod borers.

3.10.3.2 Diseases

Fungal disease was very common due to the use of gypsum. Leaf Cercospora was observed during mature stage. Fungicide was used to protect the plant from fungal infection.

3.11 Harvesting

The crop was harvested during the period from 3rd May, 2022 when the pods were fully matured. Salt treated plants were matured earlier than control plants. Harvesting was done when 90% of the pods became brown to black in color. The matured pods were collected by hand picking from each pot.

3.12 Data collection at different days after sowing

3.12.1 Morphological characters

The plant height was recorded in centimeter (cm) at 30, 45 and Harvest. Four plants were kept after thinning, and one plant taken at every sampling date for data collection from each pot.

3.12.1.1 Plant height (cm)

The plant height plant was recorded as per treatment in cm. The height was measured from the ground level to the tip of the plant by a meter scale.

3.12.1.2 Number of branches plant⁻¹

The number of branches were recorded from individual plant in each pot.

3.12.1.3 Number of leaves plant⁻¹

The number of leaves plant⁻¹ was conducted at 30, 45 DAS and at final harvest. Data were recorded from two plants from each pot and average number of leaves plant⁻¹ was recorded as per treatment.

3.12.2 Growth characters

3.12.2.1 Fresh weight of leaves, stems and roots (g)

Fresh weight of leaves, stems and roots were taken with the help of electric balance and recorded.

3.12.2.1.1 Leaves (g)

3.12.2.1.2 Stems (g)

3.12.2.1.3 Roots (g)

3.12.2.2 Dry weight of leaves, stems and roots (g)

Dry weight of leaves, stems and roots were taken with the help of electrical balance after left in an oven at 80°C for 72hours and recorded.

3.12.2.2.1 Leaves (g)

3.12.2.2.2 Stems (g)

3.12.2.2.3 Roots (g)

3.12.3 Physiological characters

3.12.3.1 Photosynthetic pigment

The leaves of mungbean plants from each treatment were taken carefully. Fresh weight of leaves (0.10g) was taken. The leaves were kept immersed in Acetone (10ml) for 24hours in

dark condition in room temperature. Then analytical procedure was done in the laboratory with the help of spectrophotometer to take the following parameters:

3.12.3.1.1 Chlorophyll a

3.12.3.1.2 Chlorophyll b

3.12.3.1.3 Total a+b

3.12.3.2 Water status

The leaves of mungbean plants from each treatment were taken carefully. Fresh weight of fully expanded third trifoliolate leaves was taken. The leaves 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. The fresh, turgid and dry weights of leaf segments were used to determine Relative Water Content (RWC), Water Saturation Deficit (WSD), Water Retention Capacity (WRC) and Water Uptake Capacity (WUC). The formula of these parameters is given below according to (Saneoka *et al.*, 1995):

3.12.3.2.1 Relative Water Content:

$$\text{RWC} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.12.3.2.2 Water Saturation Deficit:

$$\text{WSD} = 100 - \text{RWC}$$

3.12.3.2.3 Water Retention Capacity:

$$\text{WRC} = \frac{\text{Turgid weight}}{\text{Dry weight}}$$

3.12.3.2.4 Water Uptake Capacity:

$$\text{WUC} = \frac{\text{Turgid weight} - \text{Fresh weight}}{\text{Dry weight}}$$

3.12.4 Yield contributing characters

3.12.4.1 Number of pod plant⁻¹

Number of total pods of two plants from each pot were counted, and the mean numbers were expressed as plant⁻¹ basis.

3.12.4.2 Pod length (cm)

Pod length was taken from randomly selected of some pods, and the mean length was expressed as per pod basis.

3.12.4.3 Number of grains pod⁻¹

The number of grains pod⁻¹ was recorded from randomly selected pods at the time of harvest.

3.12.4.4 Weight of 100 seeds

One hundred cleaned, dried seeds were counted randomly from each harvest sample and weighed by using a digital electric balance.

3.12.5 Crop yields characters

3.12.5.1 Grain weight plant⁻¹

The grains collected from plant of each pot were sun dried properly. The weight of grains were taken and converted the grain yield in g plant⁻¹.

3.12.5.2 Stover yield

The stover collected from plant of each pot was sun dried properly. The weight of stover was taken and converted the stover yield in g plant⁻¹.

3.12.5.3 Biological yield

Grain yield and stover yield together were regarded as biological yield of mungbean. The biological yield was calculated with the following formula:

$$\text{Biological yield (g plant}^{-1}\text{)} = \text{Grain yield} + \text{Stover yield}$$

3.12.5.4 Harvest index (%)

Harvest index was calculated from the seed and stover yield of mungbean for each plant, and expressed in percentage.

$$\text{HI} = \frac{\text{Economic Yield (seed weight)}}{\text{Biological Yield (Total dry weight)}} \times 100$$

3.12.6 Nutrient Status

Laboratory analysis of plant sample

Dried seeds were ground with a Willy grinding machine for estimation of different mineral ions.

Preparation of seed extract

Exactly 1g of finely ground seeds were taken into a 250 ml conical flask and 10ml of di-acid mixture ($\text{HNO}_3 : \text{HClO}_4=2:1$) was added to it. Then it was placed on an electric hot plate for heating at 180-200°C until the solid particle disappeared and white fumes were evolved from the flask then it was cooled at room temperature and washed with distilled water and filtered into 100 ml volumetric flasks through a Whatman filter paper No. 42 making the volume up to the mark with distilled water following wet oxidation method (Jackson, 1973).

Method for chemical analysis from seeds

3.12.6.1 Sodium ion (Na^+) determination

Total Na content of the seed extract was determined by flame emission spectrophotometer and the intensity of light emitted by Na was measured wave length at 589.0nm and expressed in percentage as described by Jackson (1973).

3.12.6.2 Potassium ion (K^+) determination

Total K content of the seed extract was determined by flame emission spectrophotometer and the intensity of light emitted by K was measured wave length at 768.0nm and expressed in percentage as described by Jackson (1973).

3.12.6.3 Calcium ion (Ca^{2+}) determination

Total Ca content of the seed extract was determined by flame emission spectrophotometer and the intensity of light emitted by Ca was measured wave length at 622.0nm and expressed in percentage as described by Jackson (1973).

3.12.6.4 Nitrogen ion (N) determination

Nitrogen content in sample was determined by Kjeldahl method. The Kjeldahl method is divided into three steps. The steps include digestion, distillation and titration.

Digestion: In this method, sample was heated in the presence of sulphuric acid, potassium sulphate was added to increase the boiling point of the medium. Catalysts like mercury, selenium, copper and ions of mercury were also used in the digestion process. The sample was fully decomposed when a clear and colorless solution was obtained.

Distillation: Adding an excess base to the acid digestion mixture to convert NH_4^+ to NH_3^+ , followed by boiling and condensation of the ammonia NH_3 gas in a receiving solution was done.

Titration: An acid- base titration was performed using standard solution of hydrochloric acid and the amount of N was determined.

3.12.7. Quality

Protein content

3.12.7.1. Determination of Protein content

The amount of total N in the raw materials was multiplied with the traditional conversion factor of 6.25 to determine the amount protein from the nitrogen contents sample.

3.13 Statistical analysis

The data were analyzed statistically using the analysis of variance (ANOVA) technique with the software package R of version 3.6.0. (Gomez and Gomez, 1984) and Statistical Tool for Agricultural Research (STAR) version 2.0.1. with help of computer. The significance of the difference among the treatment means was estimated by the Least Significant Difference at 5% level of probability.

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 characteristics

4.1.1 Plant height

The plant height varied significantly due to saline stress at different days after sowing (DAS). Data revealed that the salt stress reduced the plant height of mungbean at all sampling dates. At 30, 45 and 60 DAS, the tallest plant (28.33, 48.67 and 53.67 cm, respectively) was found from T₁ (0 mM of NaCl + 0 mM of gypsum i.e., control), which was statistically different from all other treatment. But there was significant variation in plant height of BARI Mung-8 due to different levels of gypsum in saline condition. It was observed that the highest plant height (23.50, 36.43 and 47.17 cm at 30, 45 and 60 DAS, respectively) was found in T₅ (75 mM of NaCl + 45 mM of gypsum) and on the other hand the shortest plant height (8.66, 21.83 and 25.25 cm, respectively) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum). Salinity significantly reduced the plant height of mungbean varieties. However, application of gypsum fertilizer significantly improved the plant growth, and increased the plant height in all sampling dates (Table 1). The results are in agreement with the findings of Sehwat *et al.* (2015), Sarwar *et al.* (2016) who reported that salinity declined the plant growth and addition of gypsum in stressed-plants significantly increased the plant height. These finding are supported on the plant height attribute by Khan *et al.* (1992) in rice and Yadav *et al.* (2015) groundnut who reported that different levels of gypsum had significant effect on the plant height under saline and non-saline conditions, respectively.

Table 1. Effect of gypsum on the height of mungbean (BARI Mung-8) under saline environment

Treatments	30 DAS	45 DAS	Harvest
T ₁	28.33 a	48.67 a	53.67 a
T ₂	8.67 e	21.83 d	25.25 d
T ₃	12.33 d	24.57 d	28.07 d
T ₄	18.33 c	29.33 c	32.95 c
T ₅	23.50 b	36.43 b	47.17 b
T ₆	21.83 b	31.67 c	35.58 c
CV (%)	8.28	5.55	4.23
LSD	2.838	3.241	2.857

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. Data followed by same letter are not significantly different by LSD test at $p < 0.05$, CV: Co-efficient of variation, LSD: Least significant difference.

4.1.2 Number of branches plant⁻¹

The number of branches varied significantly due to saline stress at different DAS. Data revealed that the salt stress reduced the number of branches of mungbean at all sampling dates. At 45 and 60 DAS, the highest number (2.00 and 2.67 cm, respectively) was found from T₁ (0 mM of NaCl + 0 mM of gypsum i.e., control) and the lowest number (1.00 and 1.10 cm at 45 and 60 DAS, respectively) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum). Salinity significantly reduced the number of branches plant⁻¹ of mungbean varieties as reported in many studies. Similar result showed by Kandil *et al.* (2012). Nonetheless, application of Ca as gypsum fertilizer significantly increased the number branches plant⁻¹ and 45 mM gypsum T₅ (75 of mM + 45 of mM gypsum) showed the best results (1.67 and 2.33, respectively) at 45 and 60 DAS respectively.

4.1.3 Number of leaves plant⁻¹

The number of leaves varied significantly due to saline stress at different DAS. Data revealed that the salt stress reduced the number of leaves of mungbean at all sampling dates. However, the highest number (6.67, 8.00 and 8.10 cm at 30, 45 and 60 DAS, respectively) was found from T₁ (0 mM of NaCl + 0 mM of gypsum i.e., control) and the lowest number (1.33, 4.00 and 4.67 cm, respectively) was observed from T₂ (75mM of NaCl + 0 mM of gypsum) at 30,

45 and 60 DAS respectively (Table 2). Salinity significantly reduced the number of leaves plant⁻¹ of mungbean varieties. Similar result showed by Zeng *et al.* (2001). The number of leaves plant⁻¹ increased with the addition of gypsum fertilizer in this study and 45 mM gypsum fertilization produced the highest number of leaves plant⁻¹ (5.00, 6.33 and 6.67 at 30, 45 and 60 DAS, respectively) in salt-stressed plants. Similar results were observed in Khan *et al.* (2017) who concluded that seed priming with CaCl₂ mitigated the salt stress and increased the leaves plant⁻¹.

Table 2. Effect of gypsum on the number of leaves and branches plant⁻¹ of mungbean (BARI Mung-8) under saline environment

Treatments	Number of branches plant ⁻¹		Number of leaves plant ⁻¹		
	45 DAS	Harvest	30 DAS	45 DAS	Harvest
T ₁	2.00 a	2.67 a	6.67 a	8.00 a	8.10 a
T ₂	1.00 b	1.10 b	1.33 d	4.00 c	4.67 b
T ₃	1.33 ab	1.67 ab	2.00 d	5.33 bc	5.43 b
T ₄	1.33 ab	1.69 ab	3.00 c	6.00 b	6.10 b
T ₅	1.67 ab	2.33 a	5.00 b	6.33 b	6.67 ab
T ₆	1.33 ab	2.00 ab	4.67 b	5.00 c	5.35 b
CV (%)	32.64	33.01	10.44	15.04	16.94
LSD	0.8572	1.135	0.7186	1.582	1.849

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. Data followed by same letter are not significantly different by LSD test at $p < 0.05$, CV: Co-efficient of variation, LSD: Least significant difference.

4.2 Effect of gypsum on the growth characteristics

4.2.1 Fresh weight of leaves, stems and roots

4.2.1.1 Leaves

The weight of leaves as fresh condition varied significantly due to saline stress at different DAS. The results indicated that the salt stress reduced the weight of leaves in fresh condition of mungbean at all sampling dates. However, the highest leaf fresh weight (1.75, 2.53 and 3.56 gm plant⁻¹ at 30, 45 and 60 DAS, respectively) was found from T₁ treatment (0 mM of NaCl + 0 mM of gypsum i.e., control) and the lowest number (1.05, 1.17 and 1.20 gm plant⁻¹) was observed from T₂ treatment at 30, 45 and 60 DAS respectively. Gypsum fertilization in saline affected plant significantly increased the plant growth, resulting increased the number

of leaves plant⁻¹ in this study. Among the gypsum fertilization treatments, the treatment T₅ (75 mM of NaCl + 45 mM of gypsum) showed the highest leaf fresh weight. Salinity significantly reduced the leaf fresh weight of mungbean varieties as reported in studies (Hasan *et al.*, 2017, 2018). The results are in consistence with the findings of Ray and David (1992), Bello (2012), who reported that gypsum application in saline soil attenuated the adverse effects of salt stress, and increased fresh of wheat plants.

4.2.1.2 Stems

The fresh weight stems influenced significantly due to saline stress at different DAS. Salt stress reduced the fresh weight of stems of mungbean at all sampling dates of 30, 45 and 60 DAS. On the other hand, gypsum application remarkably increased the stem fresh weight in salt stressed plant. However, the highest stem fresh weight (1.89, 2.60 and 3.33 gm plant⁻¹) was recorded at the T₁ treatment (0 mM of NaCl + 0 mM of gypsum i.e., control), while the lowest stem fresh weight (0.33, 0.42 and 0.53 gm plant⁻¹) was observed from T₂ treatment (75 mM of NaCl + 0 mM of gypsum) at 30, 45 and 60 DAS, respectively. It has been reported earlier that salinity significantly reduced the stem fresh weight in mungbean (Hasan *et al.*, 2018), and application of Ca increased the plant fresh weight (Prapagar *et al.*, 2012).

4.2.1.3 Roots

The root fresh weight was significantly influenced by the saline stress at different sampling dates. The results revealed that the salt stress remarkably reduced the root fresh weight measured at different DAS. Nevertheless, the highest root fresh weight (0.33, 0.86 and 1.43 gm plant⁻¹) was recorded at T₁ treatment (0 mM of NaCl + 0 mM of gypsum i.e., control) and the lowest number (0.03, 0.24 and 0.54 gm plant⁻¹) was observed from T₂ treatment (75 of mM NaCl + 0 of mM gypsum) at 30, 45 and 60 DAS respectively. Salinity stress significantly reduced the root growth in many crops. On the other hand, application gypsum under saline condition, considerably increased the root growth and 45 mM gypsum fertilization which is T₅ (75 mM of NaCl + 45 mM of gypsum) enhanced the root growth in growth stages. It has been reported earlier that gypsum significantly increased the plant growth under saline condition in strawberry (Khayyat *et al.*, 2008). In another study, Haghghi and Naghavi (2019) concluded that CaCl₂ priming in tomato plants significantly increased the root growth under saline condition.

Table 3. Effect of gypsum on the fresh weights of leaves, stems and roots plant⁻¹ of mungbean (BARI Mung-8) under saline environment

Treatments	Leaves fresh weight (g plant ⁻¹)			Stems fresh weight (g plant ⁻¹)			Root fresh weight (g plant ⁻¹)		
	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest
T ₁	1.75 a	2.53 a	3.56 a	1.89 a	2.60 a	3.33 a	0.33 a	0.86 a	1.43 a
T ₂	1.05 e	1.17 d	1.20 d	0.33 e	0.42 e	0.53 f	0.03 d	0.24 d	0.54 f
T ₃	1.16 d	1.32 c	1.41 c	0.54 d	0.65 d	0.73 e	0.04 d	0.35 c	0.61 e
T ₄	1.23 c	1.37 c	1.46 c	0.67 c	0.74 c	0.85 d	0.042 d	0.37 c	0.76 d
T ₅	1.31 b	1.47 b	1.63 b	1.07 b	1.14 b	1.24 b	0.16 b	0.44 b	1.14 b
T ₆	1.27 bc	1.33 c	1.58 b	1.03b	1.09 b	1.17 c	0.13 b	0.31 c	0.83 c
CV (%)	0.55	0.64	0.50	1.17	0.86	0.84	9.75	6.17	2.24
LSD	0.057	0.057	0.057	0.057	0.057	0.057	0.018	0.057	0.018

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum). Data followed by same letter are not significantly different by LSD test at p < 0.05, CV: Co-efficient of variation, LSD: Least significant difference.

4.2.2 Dry weight of leaves, stems and roots

4.2.2.1 Leaves

The dry weight of leaves was affected significantly by the action of saline stress at different DAS. Salt stress reduced the dry weight of leaves of mungbean at all sampling dates. However, the highest dry weight of leaves (1.03, 1.13 and 1.41 gm plant⁻¹) was found from T₁ treatment (0 mM of NaCl + 0 mM of gypsum), whereas the lowest dry weight of leaves (0.12, 0.23 and 0.31 gm plant⁻¹) was observed from T₂ (75 mM of NaCl+ 0 mM of gypsum) at 30, 45 and 60 DAS respectively. The results are in accordance with the findings of Hasan *et al.* (2018) who noted that salinity significantly reduced the leaf dry weight of mungbean and blackgram. Inconary gypsum fertilization in salt stressed plants significantly enhanced the plant growth and leaf dry weight (Cha-um *et al.*, 2011).

4.2.2.2 Stems

The stem dry weight varied significantly due to saline stress at different DAS. The results indicated that the salt stress reduced the stems dry weight of mungbean at all sampling dates. At 30, 45 and 60 DAS the highest stem dry weight (0.65, 0.95 and 1.45 gm plant⁻¹, respectively) was found from T₁ (0 mM of NaCl + 0 mM of gypsum i.e., control) and the lowest number (0.15, 0.20 and 0.35 gm plant⁻¹, respectively) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum). It has been reported earlier that application of gypsum alleviated the salt stress effects in wheat and increased the dry weight as reported by Bello (2012). In this context, seed priming with CaCl₂ application enriches further the rhizosphere with Ca²⁺, which tends to replace exchangeable Na⁺ on the adsorption sites, and thus decreases salinity and increased the plant growth (Chen *et al.*, 2022).

Table 4. Effect of gypsum on the dry weights of leaves, stems and roots plant⁻¹ of mungbean (BARI Mung-8) under saline environment

Treatments	Leaves dry weight (g plant ⁻¹)			Stems dry weight (g plant ⁻¹)			Root dry weight (g plant ⁻¹)		
	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest
T ₁	1.03 a	1.13 a	1.41 a	0.65 a	0.95 a	1.45 a	0.080 a	0.210 a	0.540 a
T ₂	0.12 d	0.23 d	0.31 d	0.15 d	0.20 d	0.22 d	0.007 e	0.060 e	0.167 f
T ₃	0.26 c	0.37 c	0.47 c	0.24 c	0.35 c	0.41 c	0.010 d	0.064 e	0.240 e
T ₄	0.27 c	0.39 c	0.48 c	0.27 c	0.39 c	0.43c	0.013 d	0.073 d	0.340 d
T ₅	0.43 b	0.55 b	0.68 b	0.37 b	0.48 b	0.53 b	0.060 b	0.167 b	0.427 b
T ₆	0.41 b	0.53 b	0.63 b	0.36 b	0.47b	0.50 b	0.033 c	0.137 c	0.370 c
CV (%)	2.50	1.85	1.69	1.20	1.72	1.74	17.32	8.99	6.81
LSD	0.057	0.057	0.055	0.057	0.057	0.057	0.018	0.018	0.018

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. Data followed by same letter are not significantly different by LSD test at p < 0.05, CV: Co-efficient of variation, LSD: Least significant difference.

4.2.2.3 Roots

The weight of roots in dry condition varied significantly due to saline stress at different DAS. Salt stress significantly reduced the roots dry weight of mungbean plants observed at all sampling dates. However, the highest root dry weight (0.080, 0.210 and 0.540 gm plant⁻¹,

respectively) was recorded at T₁ treatment (without NaCl and gypsum i.e., control), while the lowest number (0.007, 0.060 and 0.167 gm plant⁻¹) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum) at 30, 45 and 60 DAS respectively. Salinity significantly reduced the plant height of mungbean varieties. This result is in close agreement with findings of Haghghi and Naghavi (2019) that pointed out the positive impact of CaCl₂ priming on the root dry weight of tomato plant.

4.3 Effect of gypsum on the physiological characteristics

4.3.1 Photosynthetic pigments

4.3.1.1 Chlorophyll a content

NaCl-induced salinity reduced the chlorophyll a (Chl a) content in leaves of BARI Mung-8. The highest value (0.527), of Chl a was recorded in T₁ treatment (control), and the lowest value was opined in T₂ (75mM of NaCl +0 mM of gypsum). However, foliar fertilization of gypsum ameliorated the adverse effects of salt stress, and increased Chl a content in leaves. The substantial increment of Chl a was noticed with the application 45 mM gypsum followed by 30 mM and 60 mM gypsum. This result is supported by Hossain *et al.* (2006) who reported that the application of gypsum increased the chlorophyll content in leaves.

4.3.1.2 Chlorophyll b content

The chlorophyll b (Chl b) content in leaves was reduced due to imposition of NaCl-induced stress from 0.943 to 0.657, The value of chl-b shows highest result in T₁ (0 mM of NaCl and 0 mM of gypsum) and the value of lowest result shows in T₂ (75mM NaCl and 0mM gypsum). It has been well established that salt stress declined the Chl b content in leaves in wheat (Singh *et al.*, 2021), in stevia (Zeng *et al.*, 2013). However, application of gypsum alleviated the adverse effects of salt stress, and increased Chl b contents in all gypsum treated plants under saline condition. The Chl b content gradually increased with the increasing gypsum levels up to 45 mM and thereafter decreased. This result is in close agreement with the findings of Hossain *et al.* (2006), who concluded that gypsum fertilization in saline soil enhanced the Chl b content in wheat leaves.

4.3.1.3 Total chlorophyll content

Total chlorophyll contents decreased in salt stressed-plants and it was significantly lower than that of the control plants. The value of Chl a+b showed the highest result under T₁ treatment (0 mM of NaCl + 0 mM of gypsum), and the lowest value was recorded in T₂ treatment (75 mM of NaCl + 0 mM of gypsum). Gypsum application salt-stressed plant significantly

improved total chlorophyll content in leaves, and it increased with increasing gypsum concentration up to 45 mM and then decreased the value. Hiremath and Mathad (2012) depicted that plants treated with gypsum showed increase in the chlorophyll contents at higher levels.

Table 5. Effect of gypsum on the photosynthetic pigments of mungbean (BARI Mung-8) under saline environment

Treatments	Chl a (mg g ⁻¹ FW)	Chl b (mg g ⁻¹ FW)	Chl a + b (mg g ⁻¹ FW)
T ₁	0.527 a	0.943 a	1.470 a
T ₂	0.380 c	0.657 d	1.037 b
T ₃	0.483 bc	0.810 c	1.293 ab
T ₄	0.500 b	0.887 ab	1.387 ab
T ₅	0.503 b	0.917 ab	1.420 a
T ₆	0.490 bc	0.877 b	1.367 ab
CV (%)	24.28	10.23	14.12
LSD	0.215	0.057	0.340

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. Data followed by same letter are not significantly different by LSD test at p < 0.05, CV: Co-efficient of variation, LSD: Least significant difference.

4.3.2 Water status

4.3.2.1 Relative water content (RWC)

The RWC was measured in mungbean leaf at 30 DAS. The RWC was decreased with the increasing of salinity level. However, the highest RWC (80.65) in leaf was observed from T₁ (control), while the lowest (56.12) was found from T₂ (75 mM of NaCl and 0 mM of gypsum) treatment. 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). The RWC signifies the water content in plants. In this study, mungbean was found to be suffer more due to stress than control. However, 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 mungbean also increased in all the treatments. The interaction effect of salinity and gypsum on RWC was varied

significantly. Similar findings were observed by Molazem *et al.* (2012) in study the effect of salt stress on the antioxidant enzyme activities on the leaves of maize where the RWC decreased with increasing salinity levels.

4.3.2.2 Water saturation deficit (WSD)

The WSD showed an inverse trend of relative water content (RWC). The WSD increased with the increase of salinity level in mungbean. The highest (43.88) WSD in leaf was observed from T₂ (75 mM of NaCl and 0 mM of gypsum) treatment, while the lowest (19.35) was found from T₁ treatment (control). Gypsum application positively influenced the WSD in salt-stressed and non-stressed plants. The WSD of maize significantly decreased with gypsum increasing gypsum levels. The interaction effect of salinity and gypsum on WSD was varied significantly. The highest WSD was recorded from T₂, while the lowest WSD was recorded from T₁ treatment. The WSD gradually decreased with increasing gypsum levels and statistical differences were recorded between the T₅ and T₆ treatments. 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).

4.3.2.3 Water retention capacity (WRC)

The WRC decreased with increasing salinity level in mungbean. The highest (7.42) WRC in leaf was observed from T₁ treatment (control), while the lowest (4.94) was found from T₂ (75 mM of NaCl + 0 mM of gypsum). The WRC was varied significantly with the application of gypsum in different concentrations. The WRC of mungbean increased in salt-stressed plants when the concentration of gypsum was increased. The interaction effect of salinity and gypsum on WRC was varied significantly. In salt stressed-plants, the highest WRC was recorded from interaction effect of 75 mM of NaCl + 45 mM of gypsum (T₅), while the lowest WRC was recorded from T₂ treatment combination without gypsum application. Similar result was reported by Akhtar *et al.* (2013) in wheat that plants grown under a high soil moisture regime had a higher ratio than that of the plants grown under mild stress and severe stress conditions.

4.3.2.4 Water uptake capacity (WUC)

The WUC increased with the increase of salinity level in mungbean. The WUC was higher in stress condition than normal condition. The highest (1.72) WUC in leaf was observed from T₂ (75mM of NaCl + 0 mM of gypsum), while the lowest (0.74) was found from T₁ (control). Application of gypsum in different concentrations attenuated the adverse effects of salt stress and reduced the values of WUC considerably. The interaction effect of salinity and gypsum on WUC was varied significantly. The minimum WUC in salt stressed-plants was recorded from the T₅ (75 mM of NaCl and 45 mM of gypsum) treatment. Similar effect was reported by Hossain *et al.* (2006) and Akhtar *et al.* (2013) in wheat and Francisco *et al.* (2004) in pepper plant.

Table 6. Effect of gypsum on the RWC, WSD, WRC and WUC of mungbean (BARI Mung-8) under saline environment

Treatments	RWC	WSD	WRC	WUC
T1	80.65 a	19.35 c	7.42 a	0.74 c
T2	56.12 c	43.88 a	4.94 c	1.72 a
T3	59.15 c	40.85 a	5.45 bc	1.19 bc
T4	63.83 bc	36.17 ab	6.25 ab	1.18 bc
T5	71.03 b	28.97 b	6.52 ab	1.08 ab
T6	72.06 ab	27.94 bc	6.49 ab	1.07 ab
CV (%)	7.44	15.19	10.89	19.69
LSD	9.083	9.083	1.224	0.4566

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. Data followed by same letter are not significantly different by LSD test at p < 0.05, CV: Co-efficient of variation, LSD: Least significant difference.

4.4 Effect of gypsum on the yield contributing characteristics

4.4.1 Number of pods plant⁻¹

The number of pods plant⁻¹ of mungbean showed significant variations for saline condition. The highest number of pod plants⁻¹ (16.33) was found from T₁ (0 mM of NaCl + 0 mM of gypsum), while lowest number (2.00) was observed from T₂ (75mM of NaCl + 0 mM of gypsum). Amira and Qados (2010) reported that growth parameters were significantly reduced with high salinity levels. Different levels of gypsum showed significant variations on pods per plant. The highest number of pods per plant (15.00) was observed in T₅ (75mM of

NaCl + 45 of mM gypsum) and the lowest number of pods per plant (2.33) on T₃ (75mM of NaCl + 15mM of gypsum). These results are in accordance with findings under saline conditions, where it was revealed that high level of salinity significantly decreased the number of pods plant⁻¹, while addition of gypsum alleviated the adverse effect and increased the number of pods plant⁻¹ of mungbean (Jawahar *et al.*, 2013).

4.4.2 Pod length

The pod length of mungbean showed significant variations for saline condition. The highest length of pods (6.67cm) was found from T₁ (0 mM of NaCl + 0 mM of gypsum), while the lowest length (2.70cm) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum). Amira and Qados (2010) reported that growth parameters were significantly reduced with high salinity levels. Different levels of gypsum showed significant variations on the pod length. However, the highest length of pods (4.73 cm) was observed in T₅ (75 mM of NaCl + 45 of mM gypsum), and the lowest length of pods (3.10cm) was observed in T₃ treatment (75 mM of NaCl +15 mM of gypsum). It has been reported in rice crop that gypsum application increased the panicle length under saline conditions (Ahmed *et al.*, 2021).

4.4.3 Number of grains pod⁻¹

The number of grains pod⁻¹ of mungbean showed significant variations for saline condition. The highest number of grain pod⁻¹ (8.67) was found from T₁treatment, while the lowest number of grains pod⁻¹ (2.33) was observed from T₂. The results are in agreement with the findings of Amira and Qados (2010) who reported that growth parameters were significantly reduced with high salinity levels. Different levels of gypsum showed significant variations on number of grains pod⁻¹. The highest number of grains pod⁻¹(6.33) was observed in T₅ (75 mM of NaCl + 45 mM of gypsum) and the lowest number of grains pod⁻¹ (4.44) on T₃ (75mM of NaCl +15 mM of gypsum). These findings are in harmony with those of study investigated in blackgram (Jawahar *et al.*, 2013), where it was exposed that gypsum fertilization increased the number of grains pod⁻¹.

4.4.4 100-grain weight

The 100-grains weight of mungbean showed significant variations for saline condition. The highest value (5.0 g) was found from T₁ treatment, while the lowest value (2.5 g) was observed from T₂ (75mM of NaCl +0 mM of gypsum). Similar results were also confirmed by Hasan *et al.* (2018) who reported that salt stress significantly reduced 100-grains weight of mungbean. Gypsum treated plant produced statistically significant thousand seed weight

(TSW) than without gypsum treated plants in mungbean. The result is in agreement with the findings of Ahmed *et al.* (2021), who concluded that gypsum mediated the negative effects of salt stress and increased TSW of wheat. Similar results were also reported by Liu *et al.* (2010), where in phosphor-gypsum increased the TSW of rice.

Table 7. Effect of gypsum on the number of pods plant⁻¹, pod length, number of grains pod⁻¹ and 100- grains weight of mungbean (BARI Mung-8) under saline environment

Treatments	Number of pods plant ⁻¹	Pod length (cm)	Number of grains pod ⁻¹	100- grains weight (g)
T ₁	16.33 a	6.67 a	8.67 a	5.00 a
T ₂	2.00 c	2.70 f	2.33 d	2.50 c
T ₃	2.33 c	3.10 e	4.44 c	2.70 c
T ₄	8.67 b	3.50 d	6.00 b	3.20 bc
T ₅	15.00 a	4.73 b	6.33 b	4.60 a
T ₆	10.67 b	4.17 c	5.33 bc	3.50 b
CV (%)	13.06	2.96	11.97	11.20
LSD	2.178	0.2153	1.197	0.730

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum Data followed by same letter are not significantly different by LSD test at p < 0.05, CV: Co-efficient of variation, LSD: Least significant difference.

4.5 Effect of gypsum on crop harvest/ crop yield characteristics

4.5.1 Grain yield

Salt stress significantly reduced the grains yield of mungbean in this study. The highest value (2.82 g) was found from T₁ (0 mM of NaCl + 0 mM of gypsum), while the lowest value (0.23 g) was observed from T₂ (75 mM of NaCl and 0 mM of gypsum). Data regarding gypsum application in salt stressed-plants showed that gypsum significantly attenuated the adverse effects of salt stress, and increased the grain yield than the plants where gypsum was not applied. However, gypsum @ 45 mM produced the highest yield plant⁻¹ which was statistically identical with 60 mM gypsum. Similar amelioration effect of gypsum under salt was also observed in case of grain yield by Mel *et al.* (2019) and Ahmed *et al.* (2021) in rice. Liu *et al.* (2010) showed that the application of phosphor-gypsum significantly increased the grain yield of rice.

4.5.2 Stover yield

The stover yield of mungbean showed significant variations for saline condition. The highest value (2.85 g) was found from T₁ (0 mM of NaCl + 0 mM of gypsum), on the other hand, the lowest value (0.71 g) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum). It has been reported earlier that salinity stress significantly reduced straw yield (Amira and Qados, 2010; Ahmed *et al.*, 2021). Different levels of gypsum showed significant variations on mungbean. The highest value of stover yield (1.31 g plant⁻¹) was observed in T₅ (75 mM of NaCl + 45 mM of gypsum) and the lowest value (0.88 g plant⁻¹) on T₃ (75mM of NaCl +15 mM of gypsum). These findings are similar to those reported by Liu *et al.* (2010) and Ahmed *et al.* (2021), who concluded that gypsum fertilization increased the straw yield.

4.5.3 Biological yield

The biological yield of mungbean was significantly influenced by the saline stress condition. Nonetheless, the highest value (5.76 g plant⁻¹) was found from T₁ (0 mM of NaCl + 0 mM of gypsum), while the lowest value (0.95 g plant⁻¹) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum). Different levels of gypsum showed significant variations on mungbean. The highest value (2.48 g plant⁻¹) was observed in T₅ (75 mM of NaCl + 45 mM of gypsum), and the lowest value (1.31 g plant⁻¹) on T₃ (75 mM of NaCl +15 mM of gypsum). The biological yield is reduced due imposition of salt stress (Amira and Qados, 2010; Ahmed *et al.*, 2021), in contrary gypsum fertilization under saline conditions increased the plant growth, consequently increased the biological yield of crop.

4.5.4 Harvest index

Saline stress significantly influenced the harvest index (HI) of mungbean. However, the highest value of HI (49.73 %) was found from T₁ (0 mM of NaCl + 0 mM of gypsum) treatment, and the lowest value of HI (24.46 %) was observed from T₂ (75 mM of NaCl + 0 mM of gypsum) treatment. On the other hand, different levels of gypsum showed significant variations on the harvest index of mungbean. The highest value (42.05 %) was observed in T₅ (75mM of NaCl + 45mM of gypsum), and the lowest value (32.31 %) was opined at T₃ treatment (75 mM of NaCl + 15 mM of gypsum). Hasan *et al.* (2018) reported that salt stress significantly reduced the HI of mungbean.

Table 8. Effect of gypsum on the grain yield, stover yield, biological yield and harvest index of mungbean (BARI Mung-8) under saline environment

Treatments	Grain yield (g plant ⁻¹)	Stover yield (g plant ⁻¹)	Biological yield (g plant ⁻¹)	Harvest index (%)
T1	2.82 a	2.85 a	5.76 a	49.73 a
T2	0.23 f	0.71 e	0.95 f	24.46 f
T3	0.42 e	0.88 d	1.31 e	32.31 e
T4	0.52 d	0.91 d	1.43 d	36.35 d
T5	1.17 b	1.31 b	2.48 b	42.05 b
T6	0.82 c	1.13 c	1.95 c	41.17 c
CV (%)	1.18	0.47	0.39	0.03
LSD	0.057	0.057	0.057	0.057

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. Data followed by same letter are not significantly different by LSD test at $p < 0.05$, CV: Co-efficient of variation, LSD: Least significant difference.

4.6 Effect of gypsum on nutritional characteristics

4.6.1 Na⁺ content

The Na content in seed increased with increasing the salinity level but application of gypsum significantly decreased Na content in seed (Table 9). Results showed that the highest amount of Na (30.06 mg g⁻¹ DW) was observed in T₂ treatment where no gypsum with saline. Table showed that, increasing the amount of gypsum with salt, the Na content decreased in the seed and make convenient environment for proper growth and reproductive cycles whereas lowest amount of Na (16.16 mg g⁻¹ DW) was observed in T₁ (control) treatment. This study is paralleled to study conducted by Osman and Rady (2015), where they depicted that increased Na content in salt- stressed pea plant (*Pisum sativum* L.) satisfactorily reduced due to application of sulphur. Ca through gypsum application prevents the uptake of Na⁺ from the soil solution which is very effective to aid crops tolerance to salinity stress (Bello *et al.*, 2021).

4.6.2 K⁺ content

The K content was varied with the different levels of gypsum in saline condition (Table 9). There was an inverse relationship between Na and K in seed, which meant that as NaCl stress increased, K content declined. This is consistent with the findings of previous studies (Adams and Ho, 1989; Alpasian and Gunes, 2001; Giuffrida et al., 2009) who discovered that soil salinity reduced the potassium content of plant tissues significantly. The maximum K content (39.77 mg g⁻¹ DW) was found in T₁ (control) while the lowest K content (23.04 mg g⁻¹ DW) was obtained in T₂ treatment where no gypsum with saline was used. But, Table 9 showed that gypsum application exerted significant influence on K content.

4.6.3 Ca²⁺ content

The various gypsum levels with saline condition significantly affected the Ca content in seed (Table 9). The Ca content increased with the increasing of salinity than control. However, the highest value (16.22 mg g⁻¹ DW) of Ca content in seeds was recorded from T₁ (control) treatment while the lowest value (10.47 mg g⁻¹ DW) of Ca content in seed was found in T₂ (75 mM of NaCl and 0 mM of gypsum) treatment. The results showed that gypsum application had a considerable impact on Ca content. This result is in agreement with the findings of Kitila *et al.*, (2020) who reported that gypsum fertilization in onion (*Allium cepa* L. cv. Adama red) increased the exchangeable Ca content in plants under salt stress.

4.6.4 N content

The N content of BARI Mung-8 varied significantly for different levels of gypsum in saline conditions (Table 9). The highest and lowest N content (4.58 mg g⁻¹ DW and 3.35 mg g⁻¹ DW) was recorded from T₁ (control) and T₂ (75 mM of NaCl and 0 mM of gypsum) treatment respectively. This results are in consistent with the findings of Osman and Rady (2015), who stated that S fertilization in pea plant (*Pisum sativum* L.) increased the uptake of N and P in plant tissues.

Table 9. Effect of gypsum on the Na, K, Ca and N content in seed of mungbean (BARI Mung-8) under saline environment

Treatments	Na (mg g ⁻¹ DW)	K (mg g ⁻¹ DW)	Ca (mg g ⁻¹ DW)	N (mg g ⁻¹ DW)
T ₁	16.16 e	39.77 a	16.22 a	4.58 a
T ₂	30.06 a	23.04 e	10.74 e	3.35 d
T ₃	27.52 b	26.49 d	11.33 d	3.59 c
T ₄	25.33 c	29.88 c	12.49 c	3.88 bc
T ₅	23.90 d	32.93 b	13.24 bc	4.07 b
T ₆	22.95 d	34.90 b	14.11 b	3.97 b
CV (%)	5.21	3.21	15.41	6.23
LSD	0.965	0.824	1.352	0.528

T₁: Control (0 mM NaCl + 0 mM gypsum), T₂: 75 mM NaCl + 0 mM gypsum, T₃: 75 mM NaCl + 15 mM gypsum, T₄: 75 mM NaCl + 30 mM gypsum, T₅: 75 mM NaCl + 45 mM gypsum, T₆: 75 mM NaCl + 60 mM gypsum. Data followed by same letter are not significantly different by LSD test at $p < 0.05$, CV: Co-efficient of variation, LSD: Least significant difference.

4.7 Quality characteristic

4.7.1 Protein content (%)

The protein content in percent was varied with the different levels of gypsum in saline condition (Figure 1). The highest and lowest protein content (28.63% and 20.96%) was recorded from T₁ (control) and T₂ (75 mM of NaCl and 0 mM of gypsum) treatment respectively. Application of gypsum in salt- stressed plants significantly increased the protein content as compared to without gypsum application. It has been reported that S stimulates a crop's response to salt stress by inducing the biosynthesis, transport and secretion of proteins, antioxidants and polyamines that are highly functional in alleviating various abiotic stresses (Bello *et al.*, 2021).

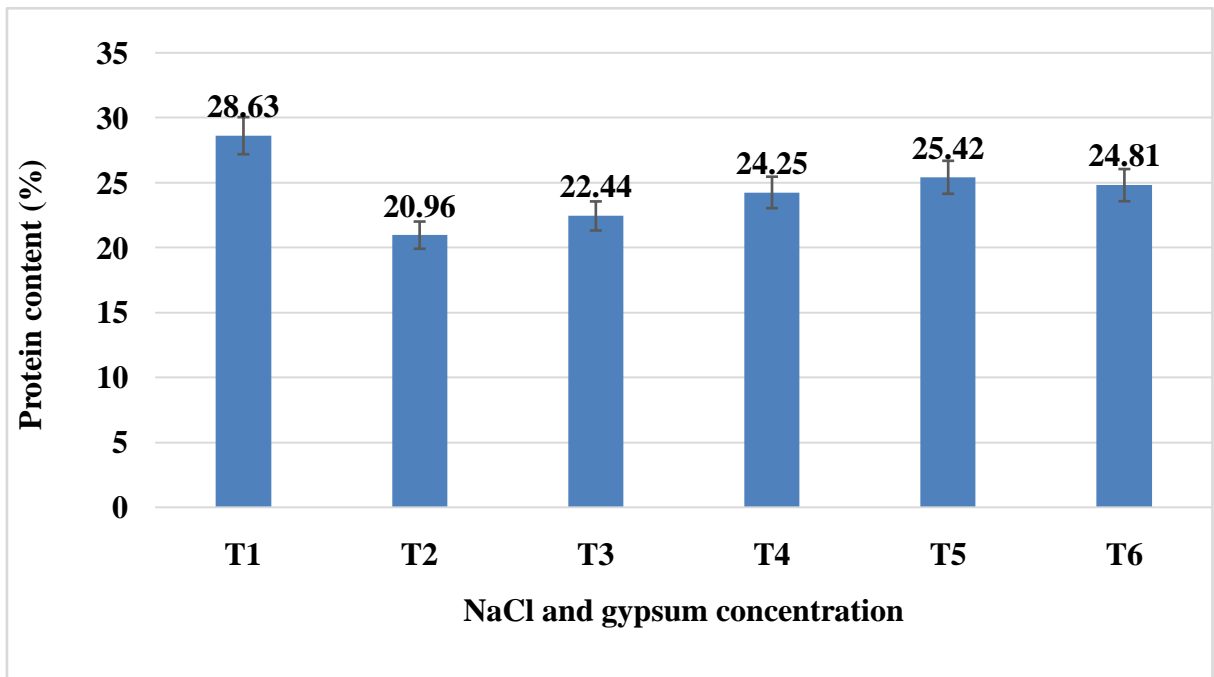


Figure 1. Effect of gypsum on the protein percentage in the grain of mungbean (BARI Mung-8)

CHAPTER V

SUMMARY AND CONCLUSION

A pot experiment was conducted at the Agronomy Pocket House, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur from March, 2022 to May, 2022 to determine the alleviation of salt stress through Gypsum in Mungbean. The experiment was single factorials which comprised of salinity level 75mM and four levels of gypsums 15 mM, 30 mM, 45 mM and 60 mM. The experiment was laid out in Completely Randomized Design (CRD) with three replications comprised six treatments viz., i) T₁ (0 mM NaCl + 0 mM gypsum), ii) T₂ (75 mM NaCl + 0 mM gypsum), iii) T₃ (75 mM NaCl + 15 mM gypsum), iv) T₄ (75 mM NaCl + 30 mM gypsum), v) T₅ (75 mM NaCl + 45 mM gypsum), vi) T₆ (75 mM NaCl + 60 mM gypsum). In the present investigation seeds of BARI Mung-8 was used. Plants were grown under saline and non-saline conditions. Twenty seeds were sown in each pot and later thinned to 8 plants per pot. Intercultural operations like thinning, weeding etc. were done when necessary. The data which were collected during the experiment are plant height (cm), number of leaves plant⁻¹, number of branches plant⁻¹, fresh and dry weight of plant parts (leaf, stem and root) (g), chlorophyll content (Chl-a, Chl-b and total Chl a+b) plant water status (RWC, WSD, WRC, WUC) of plant parts (leaf), pod length (cm), number of pods plant⁻¹, number of grain pod⁻¹, 100 seed weight (g), seed yield plant⁻¹ (g), stover yield plant⁻¹ (g), biological yield plant⁻¹ (g), harvest index (%), and nutritional properties (Na, K, Ca, N and protein content) of seeds. 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 (30 DAS, 45 DAS and 60 DAS) and the decreases was more in plants growing under NaCl stress condition. And the highest plant height was in 75mM of NaCl and 45mM of gypsum in saline condition and 0mM NaCl and 0mM gypsum in non-saline conditions. The decreases in fresh weight and dry weight of leaf, stem and root and leaf under salt stress led to reduction in all growth traits of mungbean.

From other treatments except T₁, the highest number of pods plant⁻¹ (15.00), highest pod length (4.73 cm), number of grains pod⁻¹ (6.33) which was statistically similar with T₄ (6.00) and T₆ (5.33), maximum 100 grain weight (4.60 gm), highest grain yield (1.17 gm plant⁻¹), highest stover yield (1.31 gm plant⁻¹), highest biological yield (2.48 gm plant⁻¹), highest

harvest index (41.17 %) were observed from T₅ while the lowest number of pods plant⁻¹ (2.00) which was statistically similar with T₃ (2.33), lowest pod length (2.70 cm), lowest number of grains pod⁻¹ (2.33), lowest 100 grain weight (2.50 gm), lowest grain yield (0.23 gm plant⁻¹), lowest stover yield (0.71 gm plant⁻¹), lowest biological yield (0.95 gm plant⁻¹), lowest harvest index (24.46 %) were recorded at T₂. This study reveals that salinity influenced mungbean yield and yield contributing factors, and that the application of gypsum was beneficial in relieving salt stress.

Salt stress causes significant reduction in physiological parameters. Under NaCl stress, relative water content (RWC) and water retention capacity (WRC) reduced. On the other hand, 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. Biochemical properties also significantly influenced by salinity with various doses of gypsum.

According to the preceding summary, mungbean (BARI Mung-8) can be cultivated successfully under moderate salt stress (7.5 dS/m or 75 mM NaCl stress) with the use of gypsum. The study's findings revealed that gypsum at 45 mM achieved the best performance in terms of morphological, growth, physiology, yield contributing, and yield of mungbean. As a result, mungbean (BARI Mung-8) can be grown in a saline environment (75 mM stress). This type of research is required in the southern portion of Bangladesh for regional compliance and other performance under natural saline conditions.

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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 Pocket 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 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

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

Characteristics	Value (%)
pH (Soil: water = 1: 1.25)	5.52
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 ($^{\circ}$ C)		Relative humidity (%)	Rainfall (mm) Total	Sunshine (hr) (Total)
	Minimum	Maximum			
March 2022	25.3	35.0	70.00	7.42	6.14
April 2022	25.4	36.3	59.00	7.58	6.35
May 2022	26.0	37.0	68.00	8.04	6.56

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

Appendix III: Analysis of variance (mean square) of the data for plant height (PH) of mungbean under saline environment

Source of variation	df	PH		
		30 DAS	45 DAS	Harvest
Factor A	5	160.133	277.937	370.402
Error	10	2.433	3.174	2.467

df= degrees of freedom, Factor A= Gypsum

Appendix IV: Analysis of variance (mean square) of the data for number of branches plant⁻¹ and number of leaves plant⁻¹ of mungbean under saline environment

Source of variation	df	Number of branches plant ⁻¹		Number of leaves plant ⁻¹		
		45 DAS	Harvest	30 DAS	45 DAS	Harvest
Factor A	5	0.356	1.022	12.222	5.556	4.267
Error	10	0.222	0.389	0.156	0.756	1.033

df= degrees of freedom, Factor A= Gypsum

Appendix V: Analysis of variance (mean square) of the data for fresh weight of leaves, stems and roots of mungbean under saline environment

Source of variation	df	Leaf fresh weight			Stem fresh weight			Root fresh weight		
		30 DAS	45DAS	Harvest	30 DAS	45 DAS	Harvest	30 DAS	45DAS	Harvest
Factor A	5	0.174	0.746	2.281	0.918	1.828	3.154	0.040	0.146	0.346
Error	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000

df= degrees of freedom, Factor A= Gypsum

Appendix VI: Analysis of variance (mean square) of the data for dry weight of leaves, stems and roots of mungbean under saline environment

Source of variation	df	Leaf dry weight			Stem dry weight			Root dry weight		
		30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest
Factor A	5	0.306	0.298	0.456	0.089	0.191	0.569	0.003	0.012	0.053
Error	10	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.000	0.001

df= degrees of freedom, Factor A= Gypsum

Appendix VII: Analysis of variance (mean square) of the data for photosynthetic pigments of mungbean under saline environment

Source of variation	df	Chl a	Chl b	Total a+b
Factor A	5	0.008	0.033	0.072
Error	10	0.014	0.008	0.035

df= degrees of freedom, Factor A= Gypsum

Appendix VIII: Analysis of variance (mean square) of the data for the RWC, WSD, WRC, and WUC of mungbean under saline environment

Source of variation	df	RWC	WSD	WRC	WUC
Factor A	5	250.810	250.810	2.286	0.351
Error	10	24.927	24.927	0.453	0.063

df= degrees of freedom, Factor A= Gypsum

Appendix IX: Analysis of variance (mean square) of the data for the number of pods plant⁻¹, pod length, number of grains pod⁻¹ and 100- grains weight of mungbean under saline environment

Source of variation	df	Number of pods plant ⁻¹	Pod length	Number of grains pod ⁻¹	100- grains weight
Factor A	5	111.567	3.654	13.433	3.089
Error	10	1.433	0.014	0.433	0.161

df= degrees of freedom, Factor A= Gypsum

Appendix X: Analysis of variance (mean square) of the data for grain yield, stover yield, biological yield and harvest index of mungbean under saline environment

Source of variation	df	Grain yield	Stover yield	Biological yield	Harvest index
Factor A	5	4.032	1.865	9.411	272.252
Error	10	0.000	0.000	0.000	0.000

df= degrees of freedom, Factor A= Gypsum

Some photos of my research work

